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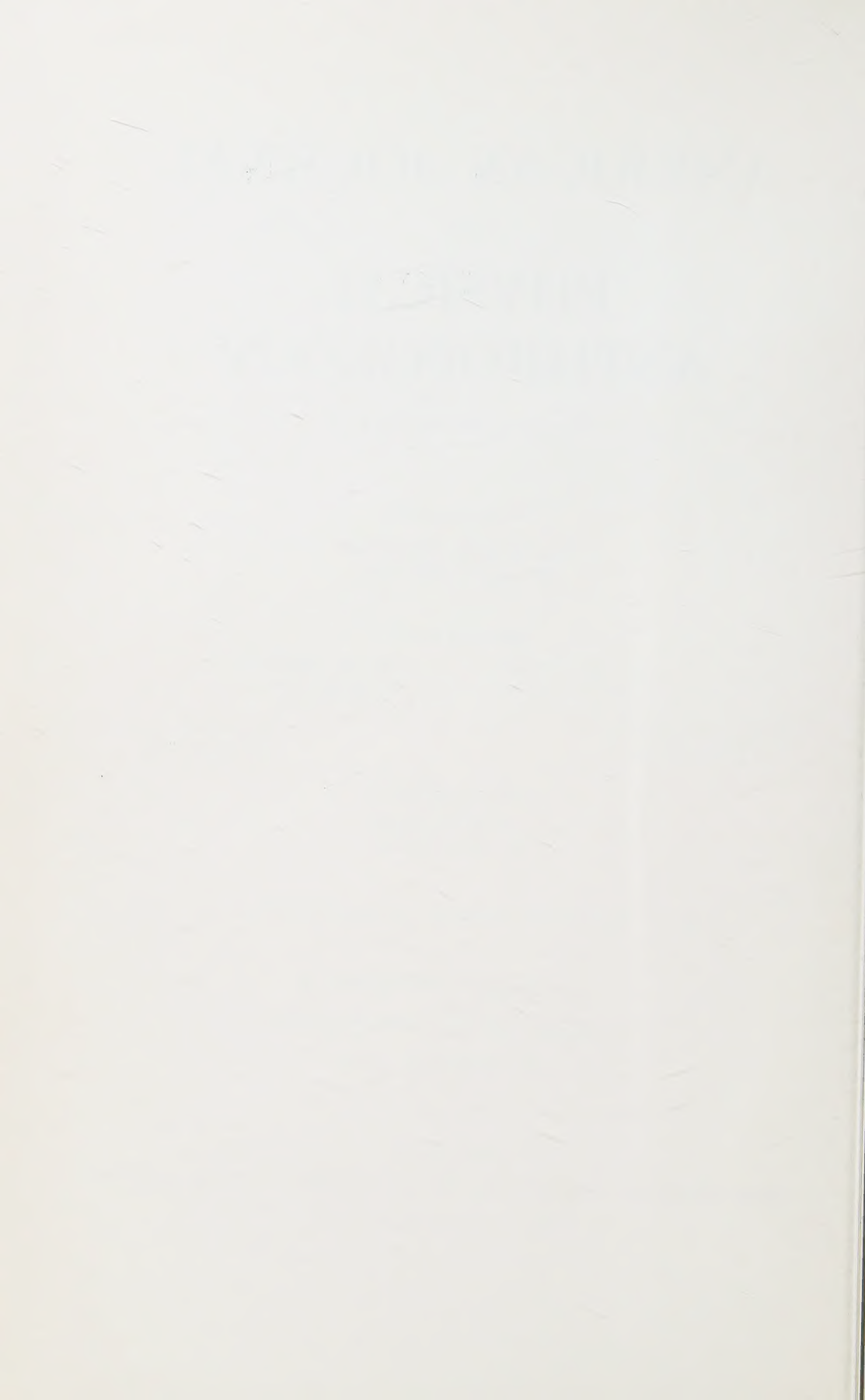
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ANTHROPOMETRY IN THE DESIGN OF THE DRIVER'S WORKSPACE¹

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TWO FIGURES

INTRODUCTION

The field of "human engineering," "biotechnology," or the design of equipment to suit human needs and capabilities, is a recent development of growing importance in industry and medicine. Working together, the human biologist and the engineer can materially improve man's comfort, efficiency, health and safety in a world increasingly man-made. The pertinent biological disciplines include anatomy, anthropology, medicine, physiology and psychology. Of these, the present paper is concerned chiefly with the anthropometric aspect of physical anthropology.

Several descriptive and historical accounts have been given of human engineering from both biological and engineering standpoints (Damon and Randall, '44, Le Gros Clark, '46, Taylor and Boelter, '47; White, '52; McFarland, 54; Roberts, '56). Scattered through various journals, and often unpublished or inaccessible in military, industrial, or university laboratories, are specialized studies too numerous to cite. They include such diverse topics as leg length and strength, hand grip and aging, range and strength of various joint motions, evaluations of specific equipment, and anthropometric

¹ This study has been sponsored by the Commission on Accidental Trauma of the Armed Forces Epidemiological Board and supported by the Research and Development Division, Office of the Surgeon General, Department of the Army.

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surveys of selected military or industrial groups. The reader is referred for further background information to five symposia ('48, '51, '54, '55a, '55b), one of them held by the Ergonomics Research Society, founded in Great Britain in 1950 to provide a meeting-ground for the varied disciplines concerned. The Human Factors Society, founded in 1957, will serve the same purpose in the United States. Both Societies publish journals.

The present paper summarizes our current thinking in an area of applied anthropometry which has been under investigation for some 15 years. Initially prepared for engineers (McFarland, Damon and Stout, '55), the factual data and design recommendations have been favorably received. Some are presented here to reach physical anthropologists and other human biologists. The values suggested for various clearances and locations may fill a need which we, as well as many others (e.g. Morant, '54) have long felt. With modification, they can serve for any seated workspace. But the actual figures are not so important *per se*. Some alternative dimensions have been suggested by Ely, Thomson and Orlansky ('56), whereas others have been more precisely defined experimentally by Dunlap ('55). In any case, the figures will vary with different groups of operators, machines, and jobs, and probably with our next progress report. Of greater interest to anthropologists may be the methods and principles employed.

One of several basic principles in human engineering is to simplify terminology and statistics. The aim of applied anthropometry is to influence design, and the engineer, not the biologist, does the designing. The engineer, not another anthropologist, is our first audience. Neglect of this principle and of its corollary, the need for actively following up recommendations, has relegated much excellent work to academic circles. Even such classical studies as Braune and Fischer's (1890) and Davenport and Love's ('21) were never put to their intended use. For this reason we have summarized, with a minimum of theoretical discussion, only the applied as-

pects of two larger publications oriented primarily toward biologists (McFarland, Damon, Stoudt, Moseley, Dunlap and Hall, '53; McFarland, Dunlap, Hall and Moseley, '53). In the present paper the use of pounds, inches, and such terms as "shoulder breadth" instead of "bideltoïd diameter" is deliberate. Technical equivalents are given in the two publications just cited.

The problem

The Highway Transport Safety Study of the Harvard School of Public Health was undertaken in 1950 in view of the serious medical and economic problems posed by accidental trauma. Accidental deaths—the largest proportion of which occur on the highway—are third among all causes of death in the United States, and first in the age range 1 to 35. Accidents are by far the largest single cause of disability. The economic damage suffered in highway accidents alone was estimated at \$4,500,000,000 in 1955.

The Harvard study was sponsored initially by the bus, truck, and automotive insurance industries, and since 1952 by the Armed Forces Epidemiological Board. The epidemiological approach, consisting of coordinated research by various specialists into those factors of host, agent, and environment that result in the "disease," offers much promise. While it will take years to identify, let alone control, all the contributing causes of accidents, an immediate and tangible, if modest, return may be expected from proper design of the "agent," or vehicle. Hence human engineering, including anthropometry, has played a part in this team effort.

Following the procedure developed for military aircraft during World War II by Hooton and others (Randall, Damon, Patt, and Benton, '46), 10 bus and 12 truck models current in 1951 were evaluated, to ascertain how well their working areas were adapted to the driver. Design features were occasionally noted which imposed unnecessary hardships on him. In some cases large men were forced into cramped positions, with insufficient room to maintain a comfortable driving position

and inadequate clearances for operating controls. On the other hand, smaller men were sometimes unable to reach controls without stretching or twisting their bodies out of a normal driving position, or were seated too low for proper vision.

To illustrate the importance of integrating the driver and his cab, an example may be cited. In one truck, a driver larger than average had difficulty placing his foot on the brake when the gearshift lever was in either of the left positions. There was too little "vertical" clearance between brake pedal and steering wheel to accommodate a tall driver's knee and leg, while the lateral space was so small that the knee could not be slipped between steering wheel and gearshift lever. Thus, the driver had to shift gears before he could operate the foot brake!

In general, it was found that inadequacies in design with regard to human dimensions fell into two categories: (1) features which might directly contribute to accidents, like the example just given, and (2) relatively minor features which of themselves might rarely result in an accident but which caused varying degrees of discomfort and annoyance. Experience has shown that such limitations are inevitably cumulative in their effects, increasing fatigue and reducing the driver's efficiency and safety.

Anthropometric survey of drivers

Many of the design deficiencies noted in the course of the cab evaluations were understandable in the absence of anthropometric data on bus and truck drivers. One cannot design properly for an unknown series of men. One of the first steps, therefore, in integrating man and machine is to determine the dimensions of the operator population. To this end 32 measurements were taken on a representative group of 360 commercial bus and truck drivers, some 200 from New England and New York, 60 from Texas, and 100 champions

from every state.² These measurements are shown graphically in figure 1. Our design recommendations are based on commercial drivers, an anthropometrically distinct group (Damon and McFarland, '55), and hence do not apply to passenger vehicles operated by men and women from the general population. Specifications for automobiles must be derived from measurements of the general driving population, but,

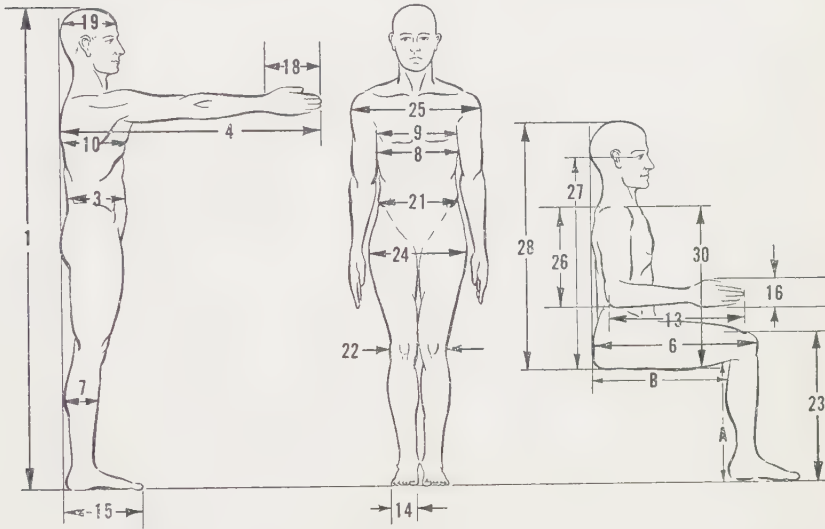


Fig. 1 Human body measurements pertinent to vehicle design. See table 1 under the appropriate number for descriptions and percentile values. Dimensions A (popliteal height) and B (buttock-popliteal length) were not measured on the drivers. (After Randall et al., '46.)

except for Hooton's ('45) limited study of railroad travelers, such data are largely lacking.

The anthropometric data in table 1 are not presented solely in terms of the "average" man, for this would give no indication of the values at the top and bottom of the group. If only averages were used in the design of a vehicle, up to 50% of a group might find many of the arrangements un-

² This phase of the study was supported by the National Association of Automotive Mutual Insurance Companies, the American Trucking Associations, and the National Association of Motor Bus Operators.

satisfactory. For example, a knee clearance just large enough for the average man will be too small for the 50% who are above average, and a control just reachable by the average man will be too distant for the 50% who are below average. Thus, the data are presented not only in terms of the average values, but of the 5th and 95th percentiles as well. Only 5% of drivers are smaller than the 5th percentile for

TABLE 1

Body dimensions of the 5th, 50th, and 95th percentiles of commercial truck and bus drivers
(in inches)

BODY MEASUREMENT	5TH PERCENTILE	50TH PERCENTILE	95TH PERCENTILE	RANGE 5TH-95TH PERCENTILE
1. Height	64.6	68.4	72.5	7.9
2. Weight (lb.)	129.0	163.7	212.8	83.8
3. Abdominal depth	7.9	9.5	12.1	4.3
4. Arm reach, anterior	32.9	35.7	38.4	5.5
5. Arm span, total	66.5	70.9	75.5	9.0
6. Buttock-knee length	22.1	23.8	25.8	3.7
7. Calf circumference (average both)	12.6	14.1	16.1	3.5
8. Chest breadth	10.2	11.8	13.5	3.3
9. Chest circumference	34.1	38.3	44.2	10.1
10. Chest depth	7.6	8.9	10.5	2.9
11. Elbow breadth	14.9	17.5	20.7	5.8
12. Elbow span	34.1	36.6	39.2	5.1
13. Elbow-middle finger length	17.3	18.8	20.2	2.9
14. Foot breadth	3.7	4.0	4.3	.6
15. Foot length	9.6	10.4	11.3	1.7
16. Hand breadth	3.2	3.5	3.8	.6
17. Hand circumference	7.6	8.3	8.9	1.3
18. Hand length	7.1	7.6	8.1	1.0
19. Head circumference	21.4	22.3	23.4	2.0
20. Head height	4.7	5.1	5.5	.8
21. Hip breadth	10.7	11.7	13.1	2.4
22. Knee breadth	7.3	8.1	9.2	1.9
23. Knee height	20.1	21.7	23.5	3.4
24. Seat breadth	13.2	14.5	16.3	3.1
25. Shoulder breadth	16.9	18.3	19.9	3.0
26. Shoulder-elbow height	13.8	14.8	15.9	2.1
27. Sitting eye height, normal	27.7	29.6	31.6	3.9
28. Sitting height, erect	34.3	36.3	38.2	3.9
29. Sitting height, normal	32.6	34.7	36.6	4.0
30. Trunk height	22.0	23.7	25.2	3.2

any given dimension, and only 5% are larger than the 95th percentile. Hence, if the design can be made to accommodate these two extremes of the population, at least 90% of all truck and bus drivers should find the arrangement satisfactory.

Ideally, the ultimate goal should be to accommodate 95, 98 or even 100% of all drivers. For this reason our recommendations should be considered as tentative minima or maxima. Additional allowances should always be made if they will not involve undue design difficulty or hardship to the middle 90% of drivers. The 5th and 95th percentiles were selected as the limits in order to accommodate as many drivers as possible without burdening the designer unnecessarily with provision for the extremes of the distribution. There would be little point in trying to accommodate the men at the outer ranges of our commercial driver series, i.e., 5' 2" and 110 lbs. or 6' 4" and 300 lbs. Designing for such an extreme range in order to accommodate only a minute additional portion of the population might be uneconomical or even prohibitively expensive. However, for some body dimensions 100% of the operators may be accommodated as easily as 90%.

For purposes of standardization, all measurements were taken on the nude body. However, since the clothing a man wears depends on climate, season, type of work, and individual preference, varying allowances must be made for personal equipment. Most clothing increases static body dimensions by a negligible amount with light summer clothing, while with heavy winter clothing it may be considerable. Combat gear can add some 50 pounds or more, with corresponding increments in body diameters which have been measured for certain outfits (Randall et al., '46). Clothing may also restrict the degree of movement, as in functional arm reach. Our recommendations are intended to accommodate the small man dressed in light summer clothing as well as the large man in heavy winter clothing. Since most of the measurements were taken in rigid, artificial postures, direct measurements were

taken of "normal" as well as "erect" sitting height and seated eye level.

Table 1 presents body measurements for the smallest drivers to be accommodated (5th percentile), the average (50th percentile), and the largest (95th percentile), based upon 360 civilian truck and bus drivers.

The driver's workspace

Anthropometrically determined dimensions of the cab area are derived from two different types of measurement of the human body. (1) Those dimensions based on *static* body measurements consist chiefly of clearances. On the whole, they are easily determined from a single body measurement and are applicable without modification to all workspaces. Examples are the various dimensions of the vehicle seat and clearances for the driver's head, knees, and abdomen. (2) Cab dimensions derived from *dynamic* human body size are based on functional body measurements. Functional reach may differ significantly from anatomical arm length. Conversely, movements of the body will change body measurements taken under static conditions; thus, a driver's reach will vary with differing shoulder positions. Again, the location of a foot control is more than a simple function of leg length. It is a combined function of such factors as leg strength, lower leg length, upper leg length, and ranges of movement at the hip, knee, and ankle. It is also influenced by seat height, which is in turn derived from seated eye level and other dimensions.

As yet, we know too little about dynamic anthropometry to specify "dynamic" cab dimensions based on static human measurements. Dempster's ('55) work offers promise along these lines. But even if we knew more about body kinematics, the complex interrelationships of human size and capabilities and equipment design would make unrealistic any specifications based on man alone, apart from his machine. Anthropometry cannot be applied in a vacuum or an ivory tower.

For design problems of the dynamic type, an experimental approach is necessary which can include both human and machine variables under actual or simulated driving conditions. If evaluation tests of a production model are being made, the vehicle itself may be used to determine the degree of driver accommodation; but if the aim is to determine criteria for future design, a cab mock-up fully adjustable in seating, controls, instrumentation, and areas of vision should be employed. To design a cab suitable for all drivers from at least the 5th to 95th percentiles in body size, one determines the adjustments necessary to accommodate a group of smaller drivers and then repeats the procedure for a group of larger men. It will probably be found that a fixed position of most controls, instruments, and window areas can be defined which will satisfy the 90% range of body size if sufficient fore-and-aft and vertical seat adjustability is available. For problems involving seat placement and design, similar experimental procedures have been followed by all human engineers since Lay and Fisher ('40).

Jointed manikins corresponding in scale to the 5th, 50th, and 95th percentiles of drivers are occasionally utilized. While they do afford an approximation of fit, their exclusive use is not recommended, since manikins cannot duplicate the biomechanical movements and posture of the human body. Hence, although they may serve in mock-ups or, in two-dimensional form, as templates in scale drawings for a preliminary guide, the degree of discomfort or difficulty of operation cannot be ascertained. The use of living manikins who approximate as closely as possible the 5th, 50th, and 95th percentiles of operators in the relevant body measurements is far superior. However, few manufacturers may be able to locate such men by anthropometric surveys in their plant. Moreover, an individual exactly at the 5th, 50th, or 95th percentile in all measurements is an unobtainable abstraction. An alternative, therefore, is to utilize *correlations* between body measurements. A person of the 5th or 95th percentile in height or weight will tend to approximate (but not exactly duplicate)

the 5th or 95th percentiles in certain other measurements. Height correlates reasonably well with body lengths, and weight with breadths, depths, and girths. Since height and weight are easily taken, a manufacturer should be able to select individuals of approximately the 5th and 95th percentiles in these respects. If enough subjects can be obtained — ideally, at least 5 for each extreme and 5 scattered through the midrange — a good idea of driver accommodation can be achieved if the subjective and objective test results are analyzed in the light of the pertinent body dimensions of these subjects, as percentiles within the driver population. A similar procedure may also be used to evaluate the static dimensions suggested in the following section.

Cab dimensions related to static human body size

The static human body measurements considered in this section permit specific recommendations for certain cab dimensions. The ones included here, for illustrative purposes, are selected from the more complete series given in McFarland, Damon, and Stoudt, '55. The present dimensions may be identified in figure 2 by the numbers given below.

1. Dimension: *Distance from seat to roof*

- (a) Pertinent Body Dimension: Sitting height.
- (b) Purpose: Clearance for driver's head.
- (c) Discussion: Insufficient head clearance may force the driver to crouch over the wheel or may cause him to strike his head on the cab roof during sudden bumps or jolts. Two inches of clearance above the erect sitting height of the 95th percentile of drivers (38.2") should generally suffice. The minimum vertical distance from the top of the seat cushion to the cab roof should thus be $40\frac{1}{4}$ ". Depression of the seat cushion by the driver's weight, plus the normal 1.8 inch slump in sitting height will give added clearance which should more than cancel out any increased height due to headgear or clothing thickness under the buttocks. With vertical seat adjustability, taller drivers will have their seats in the lower positions and shorter drivers in the higher positions.

(d) Recommendation: A minimum of $40\frac{1}{4}$ " between the top of the seat cushion and the bottom of the cab roof (if seat is adjustable vertically, a minimum of $40\frac{1}{4}$ " from the lowest position and a minimum of $36\frac{1}{4}$ " from the highest position).

2. Dimension: *Distance from top of foot pedals to lower edge of steering wheel*

(a) Pertinent Body Dimension: Knee height.

(b) Purpose: To give the driver sufficient leg room to apply the pedals without bumping or trapping his knee under the steering wheel.

(c) Discussion: This is one of the most critical cab dimensions related to human body size. Frequently when a large driver attempts to apply the foot brake, his knee either bumps the bottom of the steering wheel or his leg movements are so constricted that he must first angle his knee out to the right of the wheel, straightening the leg as the pedal is depressed. In the latter case, time is lost during a critical operation. Therefore, an absolute minimum of $24\frac{1}{2}$ " (95th percentile in knee height plus 1" shoe and clothing allowance) must be allowed between the top of the pedals and the bottom of the steering wheel. However, since this measurement is so critical it seems advisable to add at least an additional $1\frac{1}{2}$ " to accommodate the majority of drivers in the upper 5%, thus making the minimum 26" in this dimension.

(d) Recommendation: A minimum of 26" between the top surface of the foot pedals and the bottom of the steering wheel.

3. Dimension: *Distance (Horizontal) from lower edge of steering wheel to seat back*

(a) Pertinent Body Dimension: Abdominal depth.

(b) Purpose: To avoid contact of steering wheel with abdomen, and to facilitate entrance and exit.

(c) Discussion: This measurement is important for heavier drivers, who may find the steering wheel indenting their abdomens. Since the 95th percentile of commercial drivers in abdominal depth is 12.1", there should be at least 15" of horizontal clearance between the rear-most edge of the steering wheel and the seat back. This figure provides an allowance for bulky clothing and for varying postures at the wheel. Not only the tallest 95th percentile of drivers may reach the 95th percentile in abdomen depth, but some shorter men as well, since the coefficient of correlation between stature and waist depth is less than 0.20. Hence this clearance should be taken not from the rear-most position of seat adjustment but from the midpoint.

(d) Recommendation: A minimum of 15" in a horizontal line between the rearmost edge of the steering wheel and the seat back (at the midpoint of the range of fore-and-aft adjustment).

7. Dimension: *Breadth of cab seat*

(a) Pertinent Body Dimension: Seat breadth

(b) Purpose: Minimum seat breadth for comfort

(c) Discussion: In vehicles with a front seat extending across the width of the cab, this measurement will not be relevant, but where individual seats are supplied, the minimum seat width must be at least that of the 95th percentile of commercial drivers plus a suitable clothing allowance — namely, 16.3" plus 2.5", or 18.8". This is especially important where the seat is equipped with sides as in the bucket type.

(d) Recommendation: Minimum seat breadth, 19".

8. Dimension: *Seat depth*

(a) Pertinent Body Dimension: Buttock to back of knee.

(b) Purpose: To accommodate both long-and short-legged men with respect to seat depth

(c) Discussion: If seat depth is too large, short-legged drivers will find the front edge of the seat cutting into the back of the knee and will be unable to bend the knee satisfactorily unless they shift their buttocks forward on the seat. On the other hand, taller drivers will have no thigh support if the seat is too short. Buttock to back of calf distance was not taken for the commercial driver series, but comparison with a group of men measured by Hooton ('45) indicates that this dimension will approximate 17.5" for 5th percentile drivers. Although men rarely drive with buttocks tight against the seat back but rather shift forward by varying amounts, a 17-inch seat depth is the maximum that can assure comfort for 5th percentile drivers. This seat depth will also give adequate thigh support for taller drivers.

(d) Recommendation: A seat depth of 17".

11. Dimension: *Height of seat front above floor*

(a) Pertinent Body Dimension: Lower leg (popliteal) height.

(b) Purpose: To avoid excessive seat height, which results in pressure from the front edge of the seat on the under part of the thigh.

(c) Discussion: Excessive seat height is of primary concern to shorter drivers, who may find an uncomfortable pressure exerted on the under part of the thighs by the seat cushion if their feet cannot easily reach the floor or pedals. The essential body measurement in such cases is the lower leg height, from the floor to the popliteal area directly behind the knee. Although this dimension was not taken on the commercial driver series, comparisons with other groups (Hooton, '45, Hertzberg, Daniels, and Churchill, '54) indicate it to be about 17" (including shoes), for 5th percentile drivers, which suggests a seat height of 16". However, when the legs are extended forward, lower leg height is reduced, and a lower seat level is required. In general a maximum height of 15" should suffice for all drivers of the 5th percentile and larger.

(d) Recommendation: A maximum height of 15" from the top of the seat front to the floor.

12. Dimension: *Range of vertical seat adjustment*

(a) Pertinent Body Dimension: Normal sitting eye height.

(b) Purpose: Optimum location of operator's eye level.

(c) Discussion: A primary requirement in cab design is to permit drivers of varying body size to obtain optimum vision by means of vertical seat adjustment. If this is not possible, as in many present vehicles, the shorter driver may have to crane his neck or use seat pillows in order to see forward over the hood. The taller driver, on the other hand, may have to bend forward to see traffic signals or other objects above the top edge of the windshield, or bend down to avoid striking his head on the roof. Since the range of normal sitting eye height in commercial drivers is 4" (5th percentile = 27.7", 95th = 31.6"), this amount of vertical seat adjustability in one-inch increments or less will afford at least 90% of drivers a satisfactory eye level for vision. The location of the maximum and minimum points on this range must be determined experimentally, as discussed below under dynamic anthropometry.

(d) Recommendation: A minimum range of vertical seat adjustability of 4" in increments of 1" or less.

13. Dimension: *Range of fore-and-aft seat adjustment*

(a) Pertinent Body Dimension: Leg length (buttock-knee length and knee height).

(b) Purpose: Operation of foot controls.

(c) Discussion: As vertical seat adjustment is primarily dictated by requirements of the best eye level for vision, so fore-and-aft adjustment must be determined on the basis of accessibility and comfort in operating foot controls. The range of adjustment should approximate the range of drivers' leg length, slightly under 7". Although variations in the knee angle may make this full amount of adjustment unnecessary, it seems unlikely that anything less than 6" can accommodate both small and large drivers. (Among twelve 1950 truck models, 2 had no fore-and-aft adjustment, while the others ranged from 2" to 5". The lower values of this range are clearly unsatisfactory, and the maximum of 5" may not suffice for 95th percentile drivers.) The location of the maximum and minimum points of seat adjustment must again be determined experimentally, as discussed below under dynamic anthropometry.

(d) Recommendation: A range of fore-and-aft adjustment of 6" in increments of 1" or less.

Cab dimensions relating to dynamic anthropometry

As already discussed, firm specifications cannot be given at this time for certain cab dimensions, owing partly to ignorance of human biomechanics, but even more to the complex interrelationships among the many variables concerned, both human and engineering. Instead, various authors have devised experimental procedures for solving such problems in aircraft (Randall et al. '46, King '48, Morant '47), naval sighting stations (Weddell and Darcus '47), and tanks (Hugh-

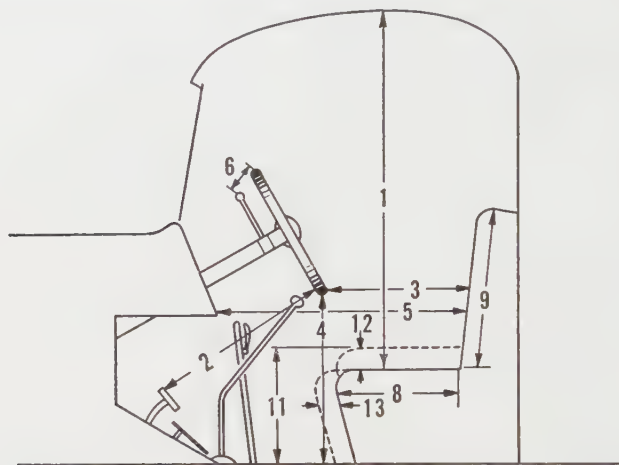


Fig. 2 Cab dimensions related to static human body size. The numbers refer to those of the dimensions discussed in the text.

Jones '47), but only recently in highway vehicles (McFarland et al. '53, Dunlap '55). Data on functional arm and leg reaches and dimensions of the workspace have been published by Ely, Thomson and Orlansky ('56). The dimensions to be discussed here concern the placement of hand and foot controls with reference to the driver's seated position.

1. *Seat locations:* The driver's seat must afford the driver maximum vision and must permit him to operate controls safely, efficiently, and comfortably. The order of procedure in locating the seat will probably be:

- (1) vertical placement of the seat for maximum vision,
- (2) fore-and-aft placement of the seat for most efficient operation of foot controls, and
- (3) placement of all hand controls and instruments with reference to (1) and (2).

(a) *Vertical seat location*: The range of vertical seat adjustment necessary to accommodate the 5th-95th percentile of drivers was stated as 4" (see Dimension 12 above). The limits of this range, however, must be determined by the experimental approach outlined previously. Using a fully adjustable mock-up with standard windshield design, a group of subjects representing the 5th percentile in normal sitting eye height should be used to determine the upper limit of adjustment. This will be the vertical position used most commonly by 5th percentile drivers to attain maximum road vision. The lower limit of the range can be similarly determined with 95th percentile subjects. With increments of adjustment of one inch or less between these limits, all drivers between the 5th and 95th percentiles will be accommodated.

This mock-up procedure should ideally be followed for all new designs. However, an *existing* design may afford inadequate provision for one, two, or even all three of the dimensions involved in vertical seat placement, namely, (1) eye level for optimum vision, (2) head clearance, and (3) popliteal (behind knee) height. When such conflicts exist, redesign is indicated, with visual requirements to take precedence.

Since the visual field is influenced by the eye-to-windshield distance as well as by vertical eye level, vertical seat location cannot be determined independently but only in conjunction with fore-and-aft seat position, as discussed below.

(b) *Fore-and-aft seat location*: The fore-and-aft location of the seat will determine whether a driver of a given body size can operate foot controls without undue stretching or constraint of the legs. The range of adjustment, calculated on the basis of leg length, has been stated above (Dimension 13) to be 6". The precise location of this range, however, must be determined by the methods just indicated, i.e., the

most forward position should be the most comfortable and efficient for 5th percentile drivers in their best vertical adjustment, and the hindmost location that for 95th percentile drivers in their best vertical adjustment. Increments of one inch or less within this range will accommodate all drivers intermediate in body size.

2. *The placement of foot controls:* The above method of fore-and-aft seat location will provide satisfactory access to foot pedals for drivers of variable leg length. In addition to the basic problem of access, however, at least three other considerations remain: (1) clearance forward of pedals, (2) lateral distance between pedals, and (3) lateral clearance for knees. With regard to (1), it has been noted that drivers frequently scrape the tips of their shoes on parts of the firewall while operating the pedals. This is a needless source of annoyance which could be eliminated through the use of the mock-up in which 95th percentile, or larger, subjects wearing winter footgear perform their normal driving activities. Where forward clearance is insufficient, the pedal might be moved back or the firewall or other offending items forward.

The lateral location of pedals can frequently be more critical. Crowded accelerator and brake pedals, especially when heavy footgear is worn, have caused operational difficulties. These include the unintentional application of one pedal while attempting to depress the other, or delay in removing the foot from the accelerator while the driver tries to avoid striking the edge or underside of the brake. Again, with insufficient resting space, the left foot must often be placed under or near the clutch. As a result, the trouser cuff or shoe welt may catch on the clutch pedal when the foot is raised from the toe pan. Lateral pedal spacing should be tested by large drivers wearing heavy shoes or boots. Sufficient clearance should be provided to avoid such difficulties as those mentioned, but distances between pedals, especially between accelerator and brake, should not be made too large, since this may increase the application time for the brake.

A final dimension involving foot pedals is lateral clearance across the legs and knees, to permit unimpeded leg movements. In some vehicles, the driver's right leg frequently touched the gear shift lever, an unnecessary inconvenience. Drivers of the 95th percentile, or larger, should again be used as mock-up subjects to test the clearance.

3. *The placement of hand controls:* The location of hand controls permits greater flexibility than that of foot controls, since a relatively wide range of movement is afforded by the biomechanics of the shoulder, arm and hand. Placement of hand controls must be considered in relation to the already established location of the seat in the various vertical and fore-and-aft positions. Since adjustability of hand controls is not generally feasible (with the possible exception of the steering wheel), a fixed location must suffice for the entire range of body size. Fortunately, the correlations of body dimensions indicate that long-legged drivers who adjust their seats in rearward positions will in general also have longer arms and will be able to reach the increased distances required by their rearward seat locations. Similarly, short-legged drivers in forward seat locations will not have to reach as far with their shorter arms.

It might at first seem that anterior arm reach could be used to indicate the maximum boundaries of the working area for locating hand controls. However, since this dimension defines only the very limited reach area directly in front of the shoulder, it cannot be used as a guide to the placement of all controls forward of the driver. Moreover, there is no completely satisfactory way of predicting functional arm reach from anterior arm length.

Thus, the procedure, once again, is to experiment with different control locations, using test subjects of the 5th, 50th and 95th percentile in body dimensions, with the seat adjusted for each subject. The body dimensions most pertinent for this purpose, in addition to height and weight, are anterior arm reach, normal sitting eye height, trunk height and shoulder breadth. The subjects should be dressed in heavy winter

clothing, which may reduce functional arm reach by one inch or more. All controls should be located where they can be easily reached by drivers within the given size range without moving from their normal driving position. Features to consider include not merely the maximum boundaries of reach but direction, sequence and distance of effective reach as well. Obstructions to free arm movement should be minimized or eliminated. Critical controls or those used most often should naturally be given priority in location.

In addition to this empirical approach, there is a more precise objective method used by King ('48) to determine the boundaries of the control area in airplane cockpits. Anthropometrically measured subjects placed in a standard seat reach for and touch successive points on a vertical measuring rod as it is moved toward the subject along a horizontal support. Trials are then repeated for varying angles to the right and left. This permits the determination of arm reach distances in the horizontal and vertical planes.

Although these reach distances will vary for each change in the conditions of the working area, such as angulation of the seat back or seat cushion, nevertheless functional reach data can be compiled for drivers of varying size under standardized conditions. Such data may be utilized in the initial stages of cab design to prevent unsatisfactory control locations which otherwise could be determined only under actual or simulated operating conditions. Investigations along these latter lines have been conducted by Dunlap ('55). Until they are published, and for application to a wider variety of machines, the approach outlined here should be useful.

DISCUSSION

A few general remarks on applied anthropometry may be in order. Physical anthropologists might well consider including some discussion of this field in courses of instruction. Students might find attractive an area which needs investigators and which can be socially useful, intellectually stimulating, and sometimes lucrative. The immediate problems can

lead to the most fundamental "pure" research, and access is afforded to that great biological unknown, the Normal Worker.

We conclude with some goals and general principles, which have proved as true for land vehicles as for aircraft, and which probably apply to all man-machine integration. There are two basic objectives of applied anthropometry. One is that all men, or as many of them as possible, be able to operate all machines. Operating conditions usually require interchangeability of personnel, but fortunately the range of human variation is small relative to machine size and is easily accommodated by adjustable devices. Few if any design defects are due to overall size limitations imposed by the machines. Most important of all, it is poor policy to restrict further the always limited supply of capable operators by imposing height and weight criteria for selection.

Another goal of applied anthropometry is to avoid limiting the machine's performance by human failure. Any machine, however cleverly engineered, may be abused or destroyed by an inefficient or uncomfortable operator. A wide margin for error should be incorporated into the design of all machines, for it cannot be assumed that every operator is continually alert, capable and efficient.

Among general principles, the following may be offered.

1. *Consider the operator.* Once this is done, all else follows.
2. *Consider him early.* Even vital and feasible redesign may cost too much in time, money and lost production ever to be effected. The earliest planning discussions, not the mock-up stage, is the time to think of human capabilities. Ideally, the machine should be considered from the outset as but an extension of a man's neuro-muscular system.
3. *The operator is functional.* He may wear bulky gear and must often perform a complex pattern of operation. He needs a clear, unobstructed view of all operations, inside and outside his workspace. He must be kept comfortable and safe, and his operation efficient.
4. *Functional men vary in size.*

5. *Allow ample margins of safety, both for man and machine.* Not only men, but also the machine should be tested operationally. In drawings and mock-ups, all accessories should be present, in facsimile if not otherwise available. Personnel experienced in the use of a machine should be consulted from the earliest planning stages and at mock-up inspections. Machine performance should be continuously checked by reports from the field, by questionnaires, unsatisfactory report forms, or best of all by personal visits of design engineers and "human factors consultants."

7. *Particular installations, not overall dimensions, cause the trouble.* Minor rearrangements will often suffice.

8. *Follow up.* This, as already mentioned, is the most important step of all if the human engineer is to achieve any practical results. This is, or should be, his personal responsibility.

Even when all has been done properly, the biotechnologist cannot count on success. Re-examination of civilian trucks 5 years after our initial studies disclosed the chastening fact that the same design errors were being made in several vehicles, despite acceptance of our findings by engineers. Administrative inertia, redesign costs and sales policies based on presumed stylistic preference by customers conflicted with sound engineering and public health practice. In passenger automobiles, more than one manufacturer has suffered financial loss as a result of public apathy toward safety features in design. Here, close to home and of daily importance to us all, is a rewarding field for the social anthropologist.

SUMMARY

Differences in human body size may have serious implications for the comfort, efficiency, and safety of vehicle drivers. Our aim has been to outline methods whereby data on human body size may be systematically incorporated into vehicular design. Previous considerations of this problem have been hampered by a lack of information on the size range of drivers to be accommodated. The engineer cannot design adequately

on the basis of an "average" man taken from the general population, without knowing precisely how "big" or how "small" his drivers will be. He must know not only static human dimensions, but also how they vary in dynamic situations.

In this report are therefore presented the 5th, 50th and 95th percentiles of 30 pertinent body dimensions of 360 commercial bus and truck drivers. Specific values are recommended for a sample of cab dimensions closely linked to human dimensions. A procedure is outlined for utilizing a mock-up, in conjunction with subjects of known size, to determine cab dimensions involving dynamic or functional human measurements. Finally, general aspects and principles of applied anthropometry are discussed.

ADDENDUM

Since this paper was submitted, the re-evaluation of trucks mentioned on p. 20 has been published (McFarland, R. A., and R. G. Domey 1958 Biotechnical aspects of driver safety and comfort. Paper 19B, Society of Automotive Engineers, New York, N. Y.)

We have also become more aware of the shortcomings of the mock-up approach, which relies too much on assumption and extrapolation rather than the firm experimental data required by the engineer. We propose to decrease spatial accommodation systematically, noting the effects on simulated driving performance.

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THE ROLE OF THE DEVELOPING EYE IN THE MORPHOGENESIS OF THE AVIAN SKULL¹

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FIFTEEN FIGURES

INTRODUCTION

The form of the vertebrate skull is the result of the interaction of many factors operating at different levels (genetic, biochemical, morphogenetic, etc.) during its development. An identification of these factors and an appraisal of the mode, sequence and extent of their influences can best be made experimentally. Indeed, the experimental approach is inescapable if we are to go beyond a simple description of vertebrate skull form and toward an understanding of the intrinsic and extrinsic forces that underlie not only the basic skull conformation of a given species, but also the observed range of variants that cluster about the norm.

The present report centers attention on the mechanical forces which, together with other factors, operate to shape the developing skull. The role of the enlarging vertebrate eye in the morphogenesis of the developing orbit has been singled out for attention first. Among mammals (Gudden, '76; Wesley '20) unilateral enucleation of the newborn leads subsequently to a smaller orbit on the operated side. Steinitz ('06) obtained similar results with the frog. Chase and Chase ('41), however, described normal orbital development in a genetically anophthalmic strain of mice; and Schultz ('40) concluded that among primates there is little dependence of the orbit on the

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eye. The seemingly divergent results obtained by reducing eye size are in contrast to consistent results obtained from experiments in which eye size was increased. When Wesseley ('20) increased the size of the rabbit eye by producing a secondary glaucoma, the size of the orbit increased correspondingly.

Similarly when, early in development, the fast growing eyes of *Amblystoma tigrinum* were heteroplastically grafted in place of slowly growing *A. punctatum* eyes, the resulting orbits were larger than those on the unoperated contralateral side (Washburn and Detwiler, '43). These authors suggested that the earlier in development enucleation or reduction of the eye size was effected the more marked would be the resulting deviation from normal orbital size. This hypothesis accounts for many, but not all, of the reported phenomena.

Little work has been done on this problem in birds where the relatively large size of the eye throughout development invites attention. Amprino ('50) noted that retardation of eye growth in the early chick embryo results in a smaller orbit later in development. Belairs ('55) effected unilateral retardation of eye growth early in chick development and obtained normal growth of the interorbital septum in subsequent development. Since bilateral operations were not performed, the conclusion of Belairs might be questioned since his procedure does not rule out the possibility that one normally expanding eye might be sufficient to maintain the interorbital septum at normal size.

The present report deals with the effects on the skull of unilateral and bilateral reduction of eye size in the chick embryo.

MATERIALS AND METHODS

The chick eggs used were from a Cornish-Rock cross incubated at 37.5°C in a forced draft incubator. All ages are recorded as days following the onset of incubation.

Controlled unilateral microphthalmia was produced by surgical intervention at the end of the fourth day of incubation. The right eye, which is uppermost at this age, was exposed by

minute incisions in the chorion and amnion. A small puncture was made in the wall of the eye at the equator to permit introduction of the end of a small glass tube (length, 3.0 mm; outside diameter, 0.4 mm; inside diameter, 0.25 mm). Thus, one end of this drainage tube rested in the vitreous chamber and the other in the amnionic cavity. The tube was left in place allowing vitreous humor to escape and thus preventing or retarding increase in the size of the eye (Coulombre, '56). Following the operation the egg was closed with cellophane tape and development was allowed to proceed until the eighteenth day of incubation. When this operation was performed bilaterally the embryo was turned on its right side within the amnion and the left eye operated upon first. After turning the embryo back on its left side the right eye was operated upon. This microsurgical procedure introduces a minimum of trauma, involves no removal of tissue and permits some control of the resulting degree of microphthalmia.

The three groups of embryos studied were: (1) unoperated embryos, (2) unilaterally operated embryos and (3) bilaterally operated embryos. In addition one "spontaneous" unilateral anophthalmic embryo was available for study.

The heads of all the animals were fixed in 95% ethyl alcohol at 18 days of incubation, by which time the bones of the skull are sufficiently large and ossified for quantitative measurements. In addition, by terminating on the eighteenth day, the hazardous terminal stages of incubation were avoided. After alizarin red-S staining and clearing in glycerin, linear measurements of the skull bones were made using a dissecting microscope fitted with a calibrated filar ocular micrometer. In all measurements parallax error was avoided.

RESULTS

By the eighteenth day the equatorial diameters of eyes which had been intubated on the fourth day ranged from 3.25 to 10.54 mm. The larger eyes were associated with orbits of corresponding size, suggesting a direct dependence of orbital upon ocular size. The smaller eyes, however, were associated

with orbits which were relatively larger than the eye, indicating that some increment of orbital growth occurs independently of an enlarging globe. Analysis of orbital height (fig. 1) as a function of eye size delimited this dependency more accurately. Those eyes which grew fast enough to achieve a diameter of 9 mm or more by 18 days had a pronounced effect

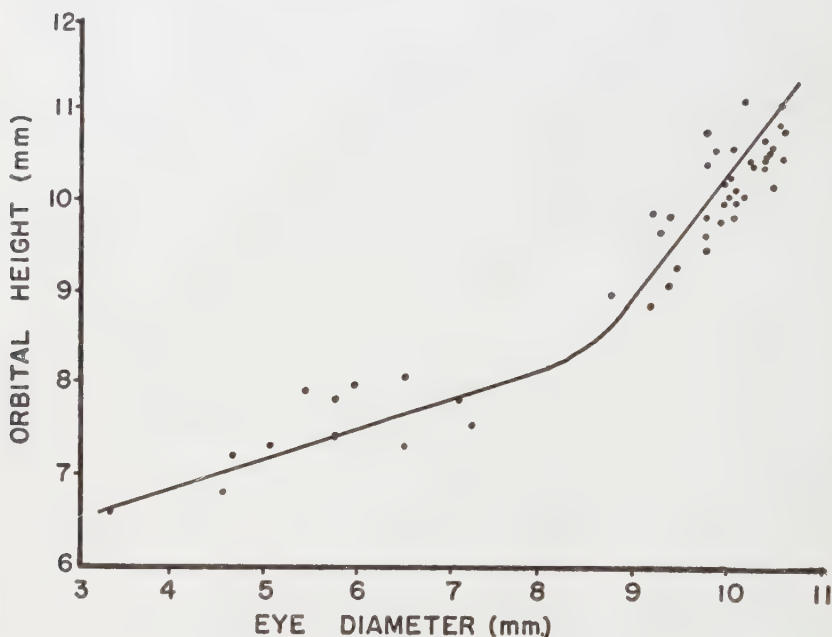


Fig. 1 Orbital height vs. eye diameter. Each point represents a single case.

upon the orbit. Eyes which have failed to attain 9 mm in diameter at 18 days had much less influence on achieved orbital size.

Since the abnormal orbital dimensions, which followed upon retardation of eye growth, resulted from deviations from the normal size, shape or position of bones surrounding the orbit, the analysis was extended to the individual bones.

The frontal bone. In those frontal bones in association with intubated eyes the supraorbital ridge was reduced or absent,

and the length of the bone was less than normal. Both effects were most pronounced in orbits containing the smallest eyes (fig. 2).

The lachrymal bone. In normal orbits the posterior surface of the dorsolateral wing of the lachrymal bone conformed to the shape of the eye at the equator, and the tip of this wing pointed laterally. In those specimens with extremely small eyes this wing has rotated posteriorly ninety degrees so that the normally posterior surface faced medially and the tip pointed posteriorly. In association with eyes of intermediate size, the lachrymal wing assumed an intermediate position. (Cf. figs. 4 through 15).

The bony arch bounding the orbit inferolaterally is the *quadratojugomaxillary complex* comprising three bones: *quadratojugal*, *jugal* and *maxillary*. In normal embryos the length of this arch was the same on each side. In the unilaterally intubated group, however, the right arch was shorter than the left. Since the three bones comprising this arch normally overlap each other, the question arose as to whether the smaller arch size was due to the failure of one or more bones to lengthen normally, to an increased amount of overlap, or to both. Appropriate analysis (fig. 2) revealed that the bones were not only shorter but also overlapped less. In addition to these differences in length the arches of experimental orbits deviated from normal in shape. Normally the arch is convex ventrally and has little or no lateral curvature. When, however, the complex developed in the presence of a small eye for 14 days, it is straight. In unilaterally operated specimens the *unoperated* orbit developed an arch which had both ventral and lateral convexity. This resulted from the crossing of the upper beak in unilaterally operated specimens, a phenomenon to be described below.

Medially the orbit is bounded by the cartilaginous interorbital septum. This differed little from normal size following unilateral or bilateral intubation of the eyes. It was, however, deviated toward the operated side in unilaterally in-

tubated specimens, but undeviated in both unoperated and bilaterally intubated specimens.

The longitudinal axis of the lower beak never deviated from the mid-line. Seven of the 10 unilaterally intubated specimens had upper beaks deviated to the right (figs. 6, 7, 10), the degree

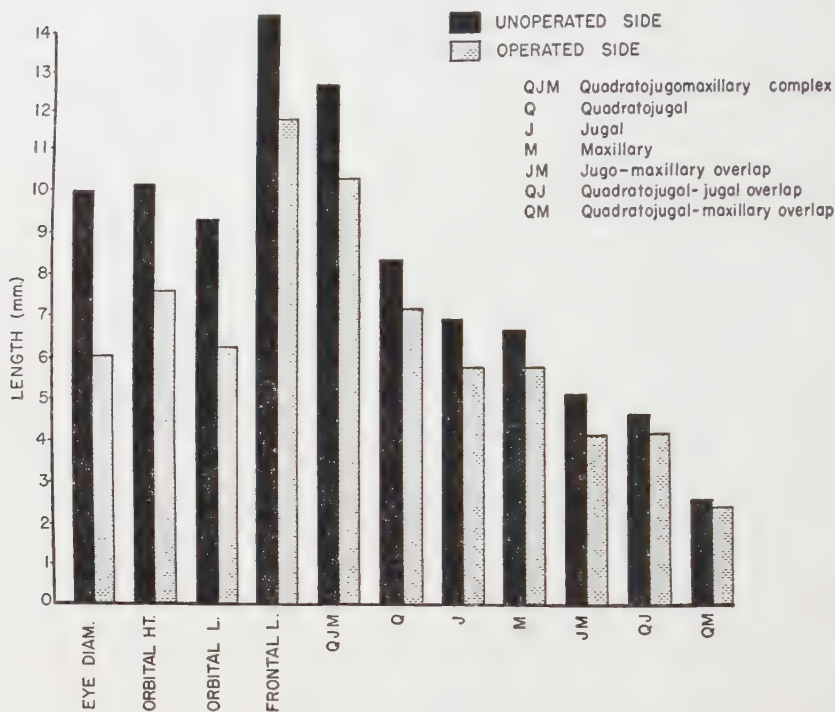


Fig. 2 Mean measurements from the operated and unoperated sides of experimental specimens.

of deviation being inversely related to the size of the right eye. The 3 embryos in which upper beak deviation did not occur possessed the largest right eyes of the unilaterally operated series. In the 4 bilaterally operated embryos there was no upper beak deviation (fig. 13).

Other general effects of ocular intubation were observed. The relatively forward position of the frontal bone in experimental orbits is associated with a widening of the fon-

tanelle (Cf. figs. 4, 7, 10, 13). In addition there were strong indications that the orientation of trabeculae in the developing bones correspond to lines of stress.

In the course of this study one "spontaneous" unilateral microphthalmic was found. It showed all of the changes in skull form which occurred in the experimentally produced condition (fig. 6).

DISCUSSION

In the chick the final size of the orbit is dependent on the degree of expansion of the globe, and thus the eye actually molds an orbit appropriate to its own size. The same situation seems to obtain in the forms studied by Gudden (1876), Weseley ('20) and Steinitz ('06). In mice, however, the eye has little to do with the shaping of the orbit, which appears normal even in anophthalmics (Chase and Chase, '41). How is it that the eye plays a dominant role in orbital morphogenesis in some species and none at all in others? The chick data suggest the following explanation.

As in other species, the presence and normal growth of the chick eye does not appear to be necessary for the differentiation and *basic* form of individual orbital bones. At most the growing eye can dictate quantitative alterations in the size, shape and position of these bones. As Amprino ('51) has pointed out, the quantitative aspects of the mechanical influence of the growing eye on surrounding structures will vary from species to species. A marked influence is to be expected in those forms (e.g. birds and amphibians) in which the eye undergoes a relatively rapid expansion during the early phases of development. In the present study the smaller orbital volume in operates as compared with controls is attributable to the sum of those changes in size, shape and position of the orbital bones which *failed* to occur in the absence of a normally expanding eye. The shapes and sizes of the orbits in association with the smallest eyes may thus be thought of as those achieved relatively independently of the growing eye (independent orbital growth). Since the growth potential of the chick eye exceeds the independent

growth potential of the orbit, in the normal course of events the growing eye is responsible for enlarging the orbit beyond the volume it would attain independently. This situation suggests that the divergent results obtained in experiments with different species might be reconciled by a scheme which takes into consideration the relationship between eye growth and orbital growth.

In species in which eye growth exceeds independent orbital growth, the orbit will become correspondingly enlarged. In such species enucleation or reduction of eye size during development will lead to the formation of an orbit below normal size. The chick typifies species in this category.

On the other hand, in those species in which the increase in eye size equals or is less than the independent growth rate of the orbit, the growing eye will exert no mechanical influence on the orbit. In such forms the removal of the developing eyes or the reduction of their size will have no effect on orbital morphogenesis. This category is typified by the mouse.

An increase in the ocular growth rate in either type should lead to an increase in orbital size. Some of these relationships are represented in figure 3.

It is clear that, if this hypothesis is correct, it bears on the postulation of Washburn and Detwiler ('43) that the magnitude of orbital effect is inversely proportional to the time during development at which the eye is experimentally altered. Their hypothesis would be inapplicable only in the case of reduction in size of the developing eye in species of the mouse type.

The interdependence of parts in the growing skull is such that influences exerted at one point affect, to some extent, all regions. The developing eye may or may not have such a widespread influence. In the chick the rapidly growing eyes extend their influence far beyond the orbital portions of the skull. These effects are revealed in the differences and asymmetries which result when one or both eyes are not allowed to expand normally. Examples of these differences in experimental specimens are the change in shape and position

of the whole frontal bone, and the greatly increased area of the fontanelle.

The changes in orientation of the upper beak effected by tapering with ocular growth reveal the basis of the cross beak condition which Landauer ('56) found associated with

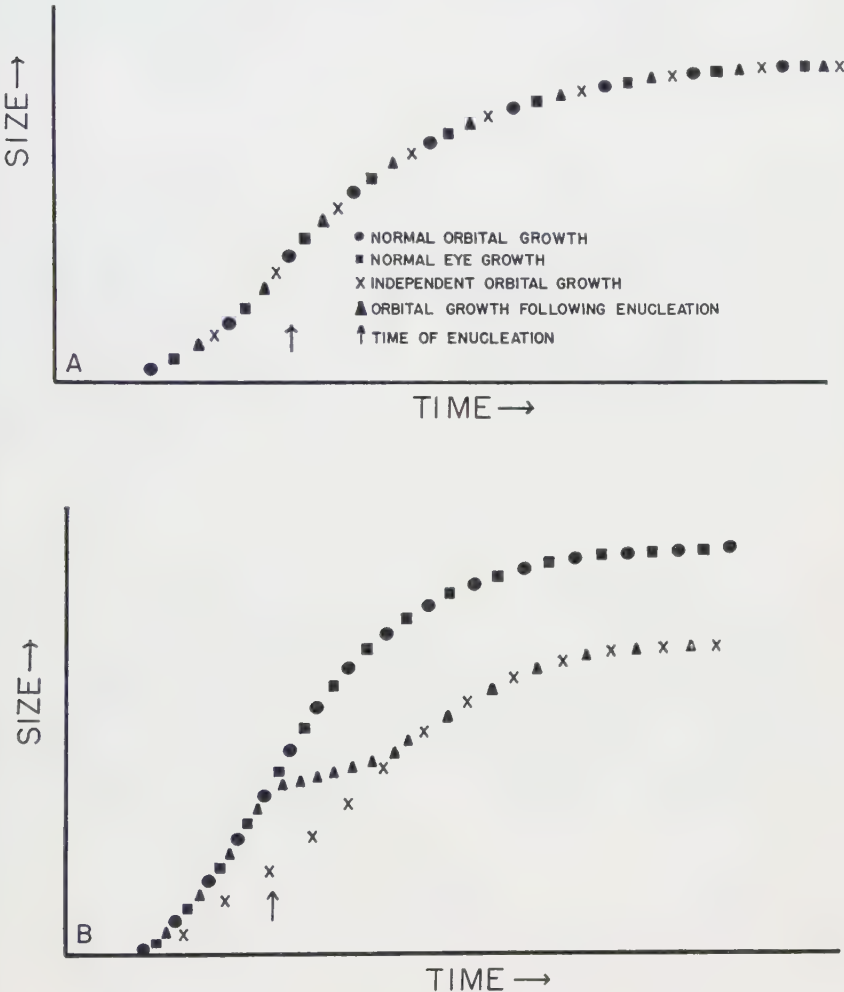
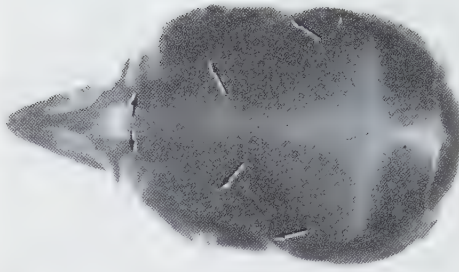
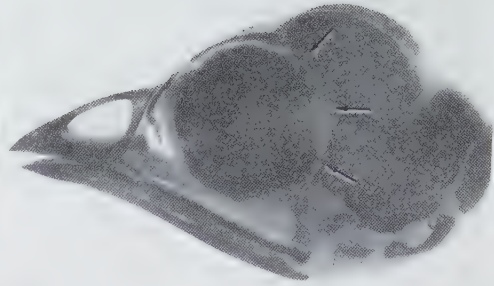


Fig. 3 Hypothetical curves. A. Illustrating the independence of orbital growth which is typified by the mouse. B. Illustrating the dependence of orbital size on the growing eye as seen in the chick embryo.



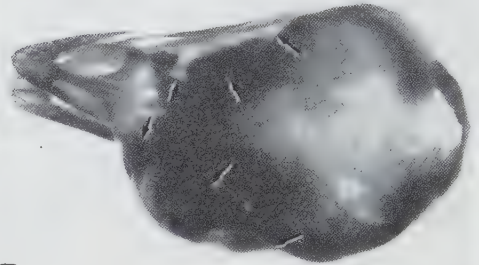
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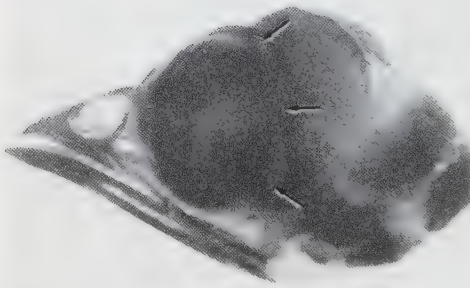
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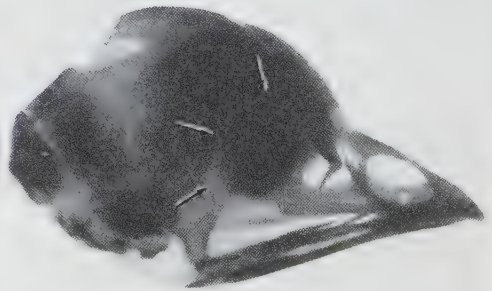
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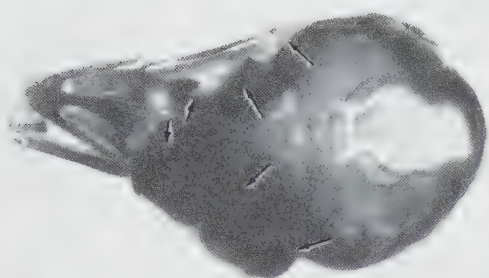
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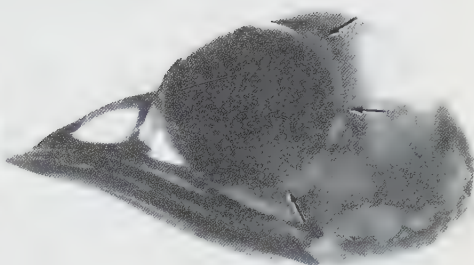
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Figs. 4-15 All specimens were fixed in 95% alcohol at 18 days, alizarin stained, cleared in glycerin and photographed by transillumination. Arrows outline orbital rim. X.

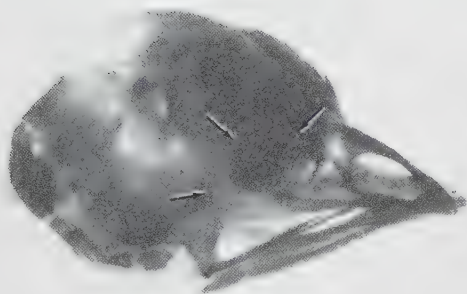
- 4 Dorsal aspect, unoperated head.
- 5 Left aspect, unoperated head.
- 6 Dorsal aspect, "spontaneous" rightsided microphthalmic.
- 7 Dorsal aspect, right eye intubated from fourth day.
- 8 Left aspect, same as figure 7.
- 9 Right aspect, same as figure 7.



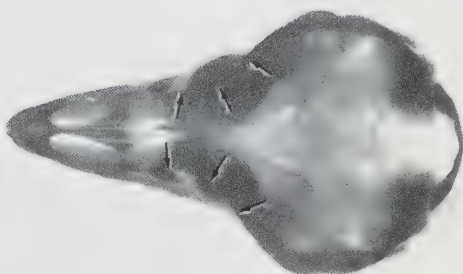
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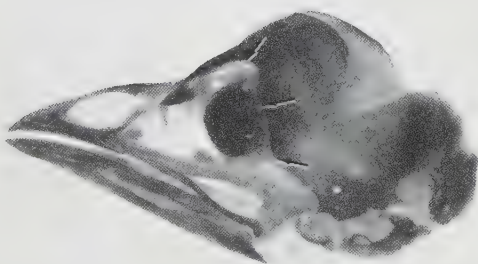
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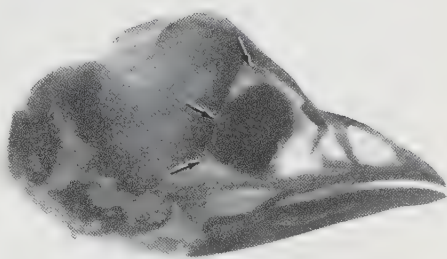
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- 10 Dorsal aspect, right eye intubated from fourth day.
- 11 Left aspect, same as figure 10.
- 12 Right aspect, same as figure 10.
- 13 Dorsal aspect, both eyes intubated from fourth day.
- 14 Left aspect, same as figure 13.
- 15 Right aspect, same as figure 13.

spontaneously occurring unilateral microphthalmia. Unilateral intubation produces ipsilateral deviation of the upper beak, whereas when both eyes are intubated the upper beak does not deviate from the midline of the head. These results give experimental support to Landauer's postulation that this variety of cross beak results from the imbalance of mechanical factors associated with differential expansion of the two eyes.

On the basis of the results of experimental reduction in size of the right eye of the chick embryo Bellairs ('55) concluded that the growth of the eye had little to do with the size of the interorbital septum. The results of bilateral ocular intubation in the present study lead to the same conclusion.

SUMMARY

1. The growing eye of the chick embryo exerts a mechanical influence on the morphogenesis of the chick orbit.
2. This influence is mediated by alterations in the size, shape and position of orbital bones as development proceeds.
3. The growing eye extends its influence beyond the orbit.
4. Alignment of the axes of the upper beak and the head is dependent, among other factors, on equal expansion of the two eyes.
5. It is hypothesized that the extent to which the developing eye influences the skull depends upon the relationship between the intrinsic growth rates of the orbit and the eye.

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THE GROWTH AND INTERRELATIONS OF SKINFOLDS AND BRACHIAL TISSUES IN MAN

P. T. BAKER¹, E. E. HUNT, JR.² AND TULIKA SEN³

ONE FIGURE

In modern physical anthropology, where interest centers on the mechanisms of somatic changes in evolution or growth, new evidence and points of view inevitably give rise to novel techniques of measurement (Washburn, '53; Lindegård, '53). In deciding what to measure, an important consideration is often what we call *parsimony*. A parsimonious dimension of the body occurs where a minimal number of growth centers or mechanisms can be identified between the boundaries of the measurement. Since different kinds of tissues usually have distinctive mechanisms of growth, a parsimonious dimension tends to encompass as few different tissues as possible.

The objective of metrical parsimony is in contrast to the concept of "components" of physique. In the somatotype, for example, Sheldon et al. ('40) claim that the mesomorphic component estimates the predominance of both muscle and bone in the body. If measurements of bone and muscle reveal that the sizes of these tissues show little covariation from one individual to another, mesomorphy clearly cannot assess the development of both tissues at once.

Since the growth centers in man lie beneath the surface of the body, we must inevitably measure the dimensions of the "inner man" if we are to describe some of the more specific events in human somatic development.

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The present study is based on the measurement of skinfolds from several sites, and of tissue shadows from radiographs of the brachium. The skinfolds were measured on cross-sectional samples of boys and girls undergoing orthodontic observation or treatment at the Forsyth Dental Infirmary for Children. Brachial radiographs were made on these children, and also on a series of young women who were students of dental hygiene at Forsyth. Finally, brachial films were also available from a group of young enlisted men of the U. S. Army. This Army sample was studied at the Quartermaster Climatic Research Laboratory at Lawrence, Mass. (now reorganized at the Natick Quartermaster Research and Engineering Center, Natick, Mass.).

Skinfolds

The scientific measurement of skinfolds dates back at least to Richer (1890), and the voluminous literature on this subject has been reviewed by Reynolds ('51) and by Keys and Brozek ('53). Efforts toward the standardization of instruments, caliper pressures and sites of measurement, however, are relatively recent.

The present study was performed with an instrument constructed at the Quartermaster Climatic Research Laboratory and described in detail by Newman ('52). The flat, circular contact surface of the instrument has an area of 30 mm². The working pressure over the usual range of skinfold thicknesses is 200 g, so that the compression of the fold is 6.7 g/mm² of caliper tip. This pressure is somewhat less than the minimum at which a linear modulus of elasticity occurs between caliper pressure and the narrowing of the fold. According to unpublished data of Sandler, this linear relationship occurs from about 10 to 90 gm/mm² of contact surface (Keys and Brozek, '53).

Some of the skinfolds measured in the present study were the same as those of Brozek and Keys ('51). In all sites, the orientation of the summit of the fold was longitudinal. The sites were as follows:

- (1) Right arm: midway from acromion to olecranon.
- (2) Right forearm: lateral to the cubital fossa, with elbow flexed 90° .
- (3) Left waist: about 5 cm lateral to the umbilicus.
- (4) Right back: immediately below the inferior angle of the scapula.
- (5) Right calf: lateral to the popliteal fossa, with the subject seated on a high stool; thigh horizontal and leg vertical.

The radiographic measurement of the brachium

Standardized radiographs of limb segments have been measured by many students of child growth and body composition. These films reveal shadows of the subcutaneous layer, deeper soft tissues (which are largely muscle and are referred to as such), and bone. When the exposure is correct within fairly narrow limits, the marrow or medulla can also be seen within the bone. This innermost shadow has not been given the attention which it deserves by previous investigators.

The measurement of these shadows has generally included lengths, breadths, or areas. On population samples, among the notable studies have been those of Ritt and Sawtell ('30), Stuart et al. ('40, '42), Reynolds ('44, '46, '48, '51), Reynolds et al. ('48), Garn ('54), Garn et al. ('53a, '53b, '55, '56a, '56b, '56c) and Best and Kuhl ('53).

In choosing limb segments for metrical radiography, the thigh and brachium contain single long bones, and are therefore simpler geometrically than the forearm and calf (fig. 1). The calf has been the most often measured, however, and authorities differ on how to measure muscle breadth. Stuart et al. ('40, '42) and Reynolds et al. ('48) have excluded the breadths of tibia and fibula. Garn et al. ('53a, '53b) have included them.

Both the arm and thigh are suitable for roentgenographic studies. The thigh contains the heaviest single bone in the skeleton (the femur), and can be used to estimate the skeletal weight of the living from the cross-sectional area of compact

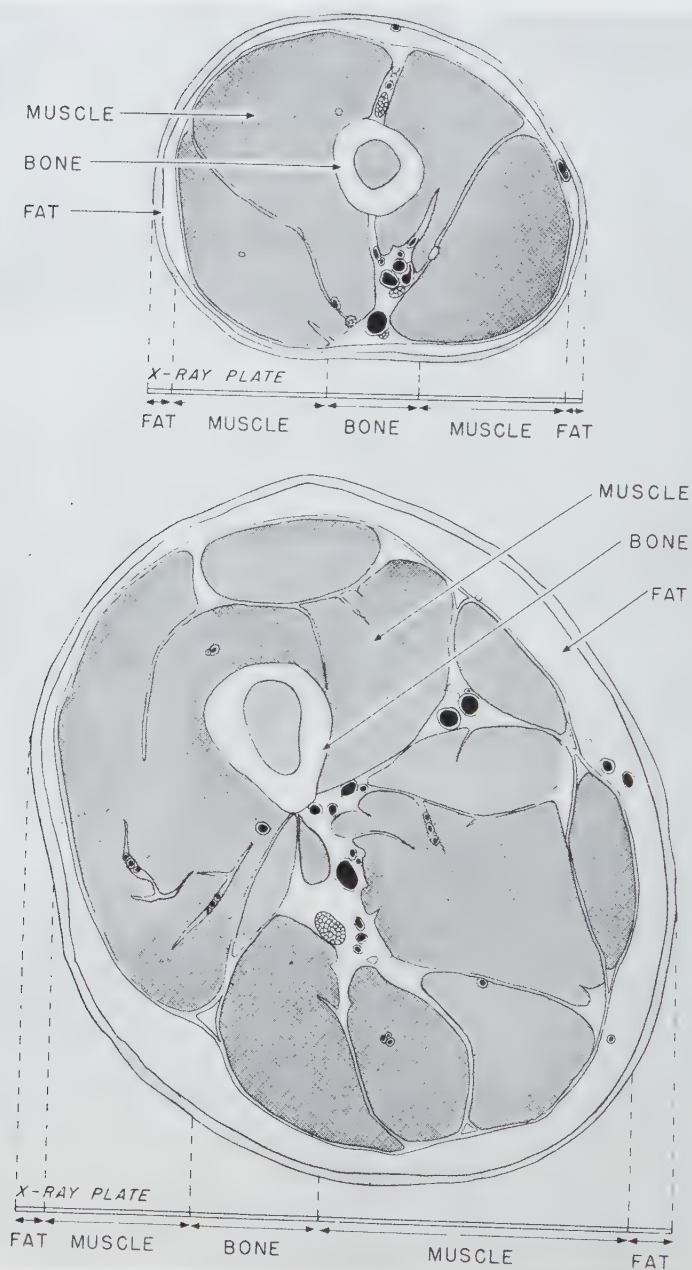


Fig. 1 Cross sections of the arm and thigh compared to X-ray views.

bone in the middle half of the femoral shadow (Trotter, '54). The predictive efficiency of equations for this purpose, however, is not high (Merz et al., '56) and in our experience, measurements of bone density must be added to new equations in order to predict skeletal weight in the living with satisfactory precision. If such densitometric methods are perfected, future studies of tissue sizes in the limbs will probably concentrate on the thigh.

The brachium, on the other hand, is more manageable than the thigh for optimal control of position and tissue deformation, and the boundaries of the marrow cavity are usually clearer in the humerus than in the femur. The brachium is also relatively easy to x-ray with a dental x-ray machine, such as the one used for our studies at the Forsyth Dental Infirmary.

The breadths of tissue shadows in the brachium are not the most accurate tissue measurements. An ordinary radiograph is a two-dimensional representation of a three-dimensional object. One possible technique is to measure the surface area of tissue shadows by planimetry, or by cutting them out with scissors and weighing the films (Stuart et al., '40).

Another possibility is to make concurrent antero-posterior and transverse films, and to reconstruct the volumes of tissues by solid geometry. Cmdr. A. P. Webster, of the Naval Medical Research Laboratory, Camp Lejeune, N.C., utilized the geometric model of frustums of elliptical conic sections in studies of the forearm. Geoghegan ('53) also used frustums for the estimation of the volume and surface area of the body from full-length nude photographs in several poses.

A simpler procedure, which we used, is to make a single film and assume that the limb segment is cylindrical. Best and Kuhl ('53) used this technique in calculating tissue volumes from an antero-posterior radiograph of the brachium in relating these volumes to basal oxygen consumption in young men.

If we adopt the fiction that the constituents of the human brachium are cylindrical, the most useful geometric trans-

formation of the raw measurements is the areas of cross-section of these tissues. The transverse cross-sectional area of the humerus at midshaft is then an estimate of the amount of compact bone produced by the periosteum by surface apposition during a given interval of growth. The area of the marrow indicates the degree to which this apposition is accompanied by endosteal resorption. The difference between the two areas indicates the amount of bone resulting at any age from these two mechanisms.

What Best and Kuhl ('53) call the "lean brachium" is the area between the two opposite superficial boundaries of the "muscle" shadow. If the total area of the humerus at midshaft is subtracted from that of the lean brachium, we can estimate the increase in the size of muscle fibers during a given interval of growth.

The rationale of this measurement is the work of MacCallum (1898) on the growth of the human sartorius muscle. By fiber counts, he found that after the second trimester of fetal life, the muscle grows by lengthening and hypertrophy rather than by an increase in the number of fibers. As Scott ('54) points out, this mechanism is generally thought to be operative for other skeletal muscles as well. A cross-sectional area of the "muscle" shadow in a suitable radiograph, then, measures the enlargement of muscle fibers to about the correct order of magnitude.

The area of the subcutaneous adipose layer is obtained by subtracting the area of the lean brachium from that of the total brachium.

The technique of making the brachial films in the present study can be seen in figure 1, where an anatomical cross section of the brachium is shown in relation to the position of the film. The subject was seated in a chair, and the right arm maintained in a horizontal position by a special wooden frame. The plate lay beneath the medial surface of the brachium with the skin in light contact with it. For the children and young women, the film-tube distance was 30". The children were given a 45 kv exposure at 40-45 milliamperes-

seconds. The young women received 55 kv at 40-45 mas. A no-screen film of 5" \times 7" was employed. The radiography of the men was similar except for a film-tube distance of 36".

This technique of radiography produces highly reliable measurements of soft tissue shadows. Of the adult males in our series, 27 were photographed on two occasions, 4 months apart. The reliability coefficient of correlation between the breadths of the humerus in the two films was .98, which equals the coefficients found in the most reliable external measurements of the living (stature and sitting height), according to Tanner and Weiner ('49). Even the breadths of the marrow cavity in the two films which have rather indefinite boundaries in some instances, showed a reliability coefficient of .92. This indefiniteness occurs because some humeri contain small amounts of cancellous bone next to the marrow at the site of measurement.

In this same adult series, a correlation was computed between the circumference of the living brachium and the breadth or maximal diameter of the radiographic shadow at the same level. This coefficient was .91. This correlation is much higher than the value of +.697, which Tanner and Weiner ('49) give as the relationship between upper arm girth and an antero-posterior breadth of this region made from well-posed body build photographs. This evidence shows that the brachium is more uniform in shape in these radiographs than under optimal conditions for photogrammetry.

The site of measurement of each film was indicated by a lead marker on the subject's skin which was in place during the radiography. This indicator was located halfway from acromion to the proximal end of the olecranon process.

The measurements at this site were taken with a machinist's vernier caliper to the nearest 0.1 mm. The basic dimensions for translation into areas included marrow breadth, total humeral breadth, lean brachial breadth and total brachial breadth. The corresponding areas of cross section were computed from the formula which yields the area of a circle

from its diameter. Letting d equal any of the brachial breadths listed above, and A represent the area of cross section:

$$A = \frac{\pi}{4} d^2$$

*The prediction of radiographic adipose
thickness from skinfolds*

Three recent papers have dealt with the translation of skinfold thicknesses into the radiographic shadows of skin and adipose tissue. Hammond ('55) found that brachial skinfolds over the triceps (our measurement No. 1), a similar fold over the biceps, and a median fold on the thigh two inches above the patella, all have similar compressibility. A single formula can therefore translate any of these folds into the radiographic equivalent. This formula was based on a sample of English children of both sexes whose numbers and ages are not specified. We designate readings from the Harpenden caliper (Edwards et al., '55) in millimeters and tenths of millimeters as x . If H equals the radiographic thickness of the subcutaneous layer, we obtain the following curvilinear equation:

$$H = 0.95 x - 0.0074 x^2$$

Garn ('56) and Garn and Gorman ('56) have compared skinfold readings (x) and uncorrected adipose thicknesses (G) taken on 65 young men aged 21-22 years. The site was lateral to the lower ribs, and the radiographic measurement taken from a standard postero-anterior chest film. We have transformed their equation into a form corresponding to Hammond's:

$$G = 0.775 x$$

The correlation between the two methods of measurement was high (0.88).

In table 1, we present regression equations from the two samples of Forsyth children. These data, like those of Garn and Gorman ('56), indicate rectilinearity of regression of radiographic thicknesses on skinfolds. In table 1, T represents

the posterior radiographic thickness of the skin and subcutaneous layer. In table 2, predicted values of radiographic thickness are given for all 4 of the available formulas.

In considering table 2, we may note that the Garn caliper and ours have the same surface area of contact (30 mm²), but the pressure of his instrument is 10 gm/mm² rather than our 6.7. Hammond's caliper has a larger contact surface (90 mm²) but the same pressure per square millimeter as Garn's.

TABLE 1

Regression equations for predicting radiographic posterior adipose thickness of brachium from skinfolds in children

SEX	N	EQUATION	est	r _{tx}
Boys	83	$t = 0.581 \times +2.042$	1.082	.911
Girls	77	$t = 0.603 \times +2.354$	1.449	.916

TABLE 2

Predicted radiographic thicknesses from skinfolds by different equations

SKINFOLD THICKNESS	FORSYTH SERIES (POSTERIOR BRACHIUM)		GARN ('56) SERIES (LATERAL CHEST)	HAMMOND ('55) SERIES (TRICEPS, BICEPS, THIGH)
	Boys	Girls	Young men	Children
3	3.8	4.2	2.3	2.8
9	7.3	7.8	7.0	8.0
15	10.7	11.4	11.6	12.6
21	14.2	15.0	16.3	16.7

The evidence indicates that the elastic properties of skinfolds somewhat depend on the site chosen, age and sex. In young individuals, the correlations between skinfolds and radiographic equivalents are high (0.8 to 0.9), so that predictive equations for particular conditions are often worth calculating (Hammond, '55). Since we have equations for only one of our sites, the mean skinfold thicknesses are published here without translation in the radiographic equivalents.

The distribution of skinfolds during growth

In boys, little or no absolute increase in skinfolds occurs in the limbs until adolescence. Since these regions are growing, the percentages of adipose tissues decrease within them. In girls, however, the skinfolds become thicker during growth,

TABLE 3
Mean skinfolds for boys and girls

SAMPLE	MEAN AGE	N	ARM	FORE-ARM	WAIST	BACK	CALF	SUM OF FOLDS
Boys	6.0	10	10.5	6.8	4.5	5.2	12.7	39.7
	8.0	16	11.2	6.4	5.6	6.2	14.5	43.7
	9.8	22	11.5	6.9	4.9	6.3	14.4	44.0
	11.9	22	10.8	6.0	6.9	6.8	13.3	43.8
	13.9	13	11.4	6.8	7.3	6.7	13.4	45.6
Men	25.2	25	13.7	—	17.1	14.6	—	
	54.6	34	15.4	—	19.6	21.5	—	
Girls	6.0	11	13.9	8.4	8.4	7.6	14.0	52.3
	8.1	13	13.0	8.4	8.3	7.2	13.4	50.3
	10.0	13	13.4	8.6	9.7	8.0	14.2	53.9
	12.2	22	15.0	8.4	11.8	9.8	15.6	60.6
	13.8	18	15.7	9.1	12.9	11.8	17.2	66.7
Women	24.0	31	21.9	—	16.2	16.0	—	
	55.4	28	26.3	—	21.1	21.9	—	

TABLE 4
Relative breadths of skinfold sites in percentages of sum of folds in boys and girls

SAMPLE	MEAN AGE	N	ARM	FORE-ARM	WAIST	BACK	CALF
Boys	6.0	10	26.4	17.1	11.3	13.1	32.0
	8.0	16	25.6	14.6	12.8	14.2	33.1
	9.8	22	26.2	15.7	11.1	14.3	32.7
	11.9	22	24.7	13.7	15.7	15.5	30.4
	13.9	13	25.0	14.9	16.0	14.7	29.4
Girls	6.0	11	26.6	16.1	16.0	14.5	26.8
	8.1	13	25.9	16.7	16.5	14.3	26.8
	10.0	13	24.8	16.0	18.0	14.8	26.4
	12.2	22	24.7	13.8	19.5	16.2	25.8
	13.8	18	23.5	13.6	19.4	17.7	25.8

even distally in the limbs, so that the percentage decrease of adipose tissue is less marked — if it occurs at all.

The growth of brachial tissues

Tables 5 and 6 present the areas of cross section of the brachial tissues and the percentage compositions of some of the brachial areas. In addition to the Forsyth series of children and young women, data are added from radiographs of young Army enlisted men who had been utilized as part of a study of tissue changes during exposure to climatic stress in the desert (Baker, '55). The measurements prior to the experiment are used here.

In absolute terms, the area of adipose tissue in boys remains fairly constant from 8 to 14 years. Since the other tissues are growing, the percentage of adipose tissue in the brachium correspondingly declines. In young men, the percentage of adipose tissue in the brachium is about half that occurring in a boy of 6 years.

Calculations of total body fat in children (Hunt and Giles, '56; Macy and Kelly, '56) agree that an average boy of 7-9 years contains about 24% of extractable fat by weight; while a young man aged 25 years contains about 14% (Keys and Brozek, '53). This decrease is not unlike the reduction in area of brachial adipose tissue.

At all ages studied, the brachium contains more adipose tissue in girls than in boys. At the young adult level the sex difference is more than two to one. In girls, the adipose area portion of total brachial area declines slightly and reaches a minimum early in adolescence. In general, however, the tissue composition of the female brachium is far more age-stable than in the male.

In considering the lean brachium, the data show that in both composition and size, the younger boys and girls are quite similar. This lack of sex difference agrees with evidence on the static dynamometry of the upper extremity. Prior to adolescence, both sexes perform equally well in such tests (Jones, '49; Morehouse and Miller, '53).

TABLE 5

Mean areas of cross section of brachial tissues in children and young adults

SAMPLE	ORIGIN	MEAN AGE	N	AREAS OF CROSS SECTION IN MM ²						
				Mar- row	Com- pact bone	Total hum- erus	Muscle	Fat	Lean bra- chium	Total bra- chium
Boys	Forsyth	6.0	9	44	122	166	1846	1275	2012	3287
		8.0	16	53	167	220	2145	1426	2365	3791
		9.8	21	63	190	253	2776	1487	3029	4516
		11.9	22	78	222	300	3102	1488	3402	4890
		13.9	13	69	267	336	3715	1486	4051	5537
Men	U.S. Army	22.5	31	125	353	478	6910	1679	7388	9060
Girls	Forsyth	6.0	11	40	131	171	1855	1733	2026	3759
		8.1	13	41	145	186	2184	1732	2370	4102
		10.0	13	49	156	205	2298	1903	2503	4406
		12.2	17	69	221	290	2954	2110	3244	5354
		13.8	18	69	236	305	3187	2231	3492	5723
Women	Forsyth	19.5	24	70	261	331	3569	3022	3900	6922

TABLE 6

Relative brachial tissue areas expressed as percentages of total brachial midsections in children and young adults

SAMPLE	ORIGIN	MEAN AGE	N	PERCENTAGES OF TOTAL BRACHIAL AREA				PERCENTAGE OF MARROW IN HUMERUS
				Mar- row	Com- pact bone	Muscle	Fat	
Boys	Forsyth	6.0	9	1.3	3.7	56.2	38.8	26.5
		8.0	16	1.4	4.4	56.6	37.6	24.1
		9.8	21	1.4	4.2	61.5	32.9	24.9
		11.9	22	1.6	4.5	63.4	30.4	26.0
		13.9	13	1.2	4.8	67.1	26.8	20.5
Men	U.S. Army	22.5	31	1.4	3.9	76.3	18.5	26.2
Girls	Forsyth	6.0	11	1.1	3.5	49.3	46.1	23.4
		8.1	13	1.0	3.5	53.2	42.2	22.0
		10.0	13	1.1	3.5	52.2	43.2	23.9
		12.2	17	1.3	4.1	55.2	39.4	23.8
		13.9	18	1.2	4.1	55.7	39.0	22.6
Women	Forsyth	19.5	24	1.0	3.8	51.6	43.6	21.1

At maturity, the male musculature in the brachium has nearly twice the cross-sectional area found in the female. According to Jones ('49), at the end of adolescence, boys are nearly twice as strong as girls in dynamometric tests. The data suggest that where endurance and circulatory efficiency do not enter the picture, the degree of sex difference in strength is roughly proportional to the difference in cross-sectional area of the brachial musculature.

Jones ('49) found that girls attain adult values of muscular strength in most dynamometric tests not long after 13 years of age: whereas marked increases occur in boys until at least late in the teens. Our data indicate that in cross-sectional area, the brachial muscles in a thirteen-year-old girl are far nearer their adult size than in a boy at this age.

The area of cross section of compact bone in the humerus at 6 years of age is greater in girls than in boys. At subsequent ages, however, boys show greater average areas of bone.

These findings resemble the data of Venar and Todd on the fresh wet macerated skeletal weights of children (White House Conference, '33). Boys have heavier skeletal weights from birth to 2½ years, when they fall below the female averages. At about 8, the boys again surpass the girls and maintain their lead thereafter.

Girls show a pre-adolescent lag in ossification followed by a spurt which is nearly at an end at 14 years. In adolescence, the periosteum is far more active in boys than in girls. Indeed, much of the ruggedness of surface markings and massiveness of bones in the adult male are probably the outcome of this burst of periosteal apposition of bone during his adolescence.

The findings on the marrow are of particular physiological interest. In the male, it enlarges in adolescence until it occupies about the same percentage of total humeral cross section in a young man as in a prepubertal boy.

In girls, however, the medulla attains its mature area at 12 years — earlier than any other brachial tissue. The peri-

osteum, however, continues to produce bone on the superficial aspect of the humerus for a few more years.

This early end of medullary growth in girls recalls one of the endocrine mechanisms in the rat. When estrogen is injected into an immature animal, the resorption of the spongiosa within a long bone is inhibited (Budy et al., '52). This response may be a storage of calcium in preparation for pregnancy and lactation.

The response of the human female skeleton to estrogen is probably not so simple. Although osteoporosis sometimes occurs at menopause in women, estrogen therapy generally does not fully restore the original radiographic density of the skeleton. This therapy does, however, often produce positive calcium balance (McLean and Urist, '55).

It is also noteworthy that the attainment of a mature medullary area in girls coincides with a rapid rise in the titer of urinary estrogen (Nathanson et al., '41). Whether these two phenomena are causally related is not yet certain.

Interrelations among brachial tissues

In the oldest sample studied (the Army men), where growth was not an important factor, it was considered worthwhile to calculate correlations among the 4 basic tissue areas of the brachium: Marrow, compact bone, muscle and adipose tissue. The findings on the 31 men are presented below.

	COMPACT BONE	MUSCLE	ADIPOSE TISSUE
Marrow	+ 0.27	+ 0.17	+ 0.03
Compact bone		+ 0.36	+ 0.03
Muscle			+ 0.26

None of the preceding coefficients was significantly greater than zero at the 1% level of significance, and only the compact bone-muscle correlation was significant at the 5% level. In other words, the brachial tissues exhibit a great deal of independence of size at maturity.

Reynolds ('44) demonstrated the same independence in a series of 58 boys and girls at the age of 7½ years. He found that the total bone breadths and total muscle breadths (including bone) in the calf of the leg showed a correlation of —0.17.

This independence of size of constituents of the limbs has many implications which can only be touched on here. Primarily, this finding is a strong justification for the separate measurement of tissues in studies of growth, body composition or constitution.

Recent studies of body composition have validated some, but not all, of the current techniques of assessing body build. For example, the endomorphic component of Sheldon et al. ('40) is one of the better superficial estimates of total body fat in young men (Brozek and Keys, '52; Dupertuis et al., '52).

The second component (mesomorphy) is allegedly an estimate of three anatomical trends: the breadth of shafts and joints of long bones, the thickness of cortical bone, and the sizes of skeletal muscles. Since the areas of cross section of marrow, compact bone and muscle in the brachium at best exhibit only slight covariation, it is obviously impossible to make an accurate assessment of all three tissues at once by means of a single rating scale. Furthermore, as Harper ('54) points out, radiographic widths of bones and muscle are correlated slightly or not significantly with ratings of mesomorphy from body build photographs. If we regard mesomorphy as a useful scale for certain studies of body function and behavior, we need not overstate its quite tenuous basis in the tissue composition of the organism. Mesomorphy is an external assessment of the prominence of skeletal muscles in the living, and of certain body proportions which are extraordinarily difficult to measure.

The lack of significant correlation between bone and muscle sizes indicates that we should not exaggerate the interdependence of these two tissues in their amounts and patterns

of growth and that bone and muscle throughout life are semi-independent body components.

Parsimonious measurements, then add order and simplicity to some research in physical anthropology, and may restrain us from expecting too much of either external or skeletal anthropometry.

SUMMARY

A set of latero-medial radiographs of the brachium were taken in a series of children and adults of both sexes. On the children, skinfolds were also measured. The radiographic tissue shadows were transformed into areas of cross section of the brachium so that the growth of the marrow cavity, compact bone of the humerus, musculature and subcutaneous adipose layer could be measured separately. These areas were chosen to assess "parsimoniously" the growth of these tissues.

Like previous investigators, we found that skinfolds efficiently predict the radiographic thickness of skin plus subcutaneous tissue. Specific equations, however, are probably needed for specific sites, age ranges, and perhaps even in some cases for males and females.

As earlier workers have noted, females tend to have thicker skinfolds than males at all ages past early infancy. The relative concentration of this tissue in the trunk in girls is exaggerated after pubescence.

In the brachium, boys show a decline in the percentage of adipose tissue from childhood to maturity. Girls show a far smaller decline until pubescence, and then a small increase. At all ages, the average female brachium is more adipose than that of the male, and in the young adult the sex difference is more than two to one. The age-stability of composition of the female brachium apparently corresponds to an equal stability of body composition in the female which seems to begin no later than 10 years of age.

In both sexes, the lean brachium has a similar size and composition until about 10 years of age. In older boys, the

size of the brachial muscles nearly doubles while girls show only a slight increase in muscle mass.

At 6 years of age, the female brachium contains more compact bone than that of the male. At 8 years of age and older, humeral area is greater in males. In adolescence, the periosteum is far more active in boys than in girls, and this may produce the rugged surface details and massiveness of the mature male skeleton.

In boys, endosteal resorption keeps pace with periosteal apposition through adolescence. In girls, however, the marrow cavity reaches its adult size by 12 years of age. Some connection may exist between this cessation of growth and the great increase of estrogen secretion at this age.

In the adult male series, the correlations among the cross-sectional areas of marrow, compact bone, muscle and subcutaneous adipose tissue are all low, and most were not significantly greater than zero. This independence of size of brachial tissues justifies the separate measurement of each constituent in researches on mechanisms of growth. This finding also discredits the anatomical basis of the mesomorphic scale of constitutional assessment, which is supposedly based on the covariation of bone width, cortical thickness and muscle size. The lack of significant correlation between bone and muscle sizes emphasizes that one should not exaggerate the interdependence of these tissues in their amounts and patterns of growth.

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A BLOOD GROUP GENETICAL SURVEY IN AUSTRALIAN ABORIGINAL CHILDREN OF THE CAPE YORK PENINSULA ¹

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ONE FIGURE

The Aboriginal Reserve, which extends as a thin coastal strip some 20—30 miles in width on the eastern shores of the Gulf of Carpentaria for almost the entire length of the Cape York Peninsula, is the homeland of several aboriginal tribes which are among the most isolated in the Australian Continent. This region has no cattle stations or white settlements other than five mission stations, which were established between 1890 and 1938. Although Malay contacts on the western side of the Gulf of Carpentaria seem to have been considerable, there is no evidence to suggest any such contacts along the more treacherous east coast of the Gulf. The cultures retain no memory of early Dutch or English navigators who may have landed along the coast. In the late Nineteenth and early Twentieth centuries cattle stations encroached from the east upon the tribal hunting grounds, and occasionally police raids in reprisal for cattle spearing were made in the aboriginal territory, while sandalwood-getters made brief visits into the region. In spite of this, the natives long resisted complete disorganization of their traditional tribal culture. Today, al-

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though greatly modified by the presence of missions, large vestiges of tribal organization still remain.

The total aboriginal population of the region is now under 1500 and there are only a few dozen white people living in the entire Reserve. The number of extinct or almost extinct clans and the presence of extensive traditional hunting territory currently unoccupied, suggest a former population of two to four times that now present. In all of the areas of this Aboriginal Reserve, there are men who have worked on pearling luggers or on cattle stations, but they are in a minority except at Mapoon. In the vicinity of each mission there are natives who still live on their hunting grounds, and this is particularly true in the Edward River region where a mission was not established until 1938, but the majority of natives either live at the mission station or move to and fro between the mission and the hunting grounds.

The aborigines in the region of each mission station belong to the tribes originally occupying the mission site and the adjacent areas, and there has been very little shifting of the traditionally tribal-domain-bound natives from one mission to the other. At Mapoon however, there is a large population of natives of mixed blood, while only a few local tribal people remain. Those of mixed blood are Australian aborigine crosses with Melanesians, Malays, Chinese, Polynesians and Whites. At other settlements caste people are rare, and the majority of the natives are regarded as full-blooded. No difficulty was encountered in locating individuals who were of recent mixed blood, for these natives are known to the mission staff, and to the natives themselves.

In June 1956 one of us (D.C.G.) made a medical expedition with Dr. T. O'Leary of the Queensland Flying Doctor Service to each of the five aboriginal mission stations on this coast in order to make a survey of the region for establishing long-term child growth and development studies. Blood specimens were also collected for biochemical studies and for serological examination for antibodies to various virus and rickettsial diseases, with particular reference to measles. During this trip

visits were made to the two Church of England Missions, Mitchell River Mission on the Magnificent Creek, and Edward River Mission between the Edward and Holroyd Rivers, and to the three Presbyterian Missions, Aurukun Mission at the mouth of the Archer River, Weipa Mission at the mouth of the Embley River, and Mapoon Mission on Cullen Point at the entrance to Port Musgrave. (See map.) Edward River Mission had never previously been visited by the Flying Doctor, and landing was achieved on a tidal salt pan some 6 miles from the mission, after cautious testing of the surface with the weight of the Drover aeroplane.

The twenty early investigations on the A-B-O blood groups in the Australian aborigines have been cited by Birdsell and Boyd ('40), while Simmons, Graydon and Semple ('54) presented a bibliography for the intervening years. The most recent survey has been one at Haast's Bluff, Central Australia, the results of which have been presented by Simmons, Semple, Cleland and Casley-Smith ('57).

Tribes represented at each mission area

For the following tribal data we have largely drawn on McConnel ('30, '30, '34), Sharp ('34, '34) Mackenzie (personal communication), Douglas (personal communication), Winn (personal communication) and Thompson (personal communication).

Mitchell River. The Mitchell River Mission aborigines belong to three tribal groups which have extensively intermarried in recent years; the Koko-Bera (Kukaberra), Kunjin, and Koko-Manjoen (Kokominjan, Yir-Yoront). There are 350-400 full-blooded natives and a few mixed bloods settled in three aboriginal villages at the mission station, and the vast majority of the aborigines are either fully or partly sedentary, returning occasionally to their hunting and ceremonial life in the bush. The majority of men are working on cattle stations or droving at least six months of the year. During the dry season there would be no more than 100 adults left on the

mission, and of those 25 are permanently employed on the mission.

The Yir-Yoront tribal territory is on the west coast of Cape York Peninsula, including the mouth of the Coleman River and the three widely separated mouths of the Mitchell River, its coastal extent along the Gulf of Carpentaria being 30-40 miles. This region lies 350 miles south of Cape York, and is bisected by the 15th parallel of south latitude. The Koko-speaking tribes which surround the Yir-Yoront refer to them as Koko-Manjoen (Koko-meaning "speech"). In 1934 the tribe still numbered about 200 individuals, all full-blooded with one-quarter living at the Mitchell River Mission and the rest on tribal lands. The numbers of extinct or almost extinct clans and the unoccupied hunting territory suggest a much larger former population.

South of the Nassau River, the southern limit of the Yir-Yoront, are the Koko-Bera and Koko-Papun who have had antipathetic relations with the Yir-Yoront. To the north they are bordered by the Koko-Taiyor (Koko-Daiyuri)—a tribe whose clan lands extend to just north of the Edward River—who are the least disturbed tribe on Cape York Peninsula and have long been allied to the Yir-Yoront by intermarriage and common custom, although they are linguistically divergent. These two allied tribes have traditionally had little association with the Wik-speaking tribes to the north or the Koko-speaking tribes to south. Inland of the Yir-Yoront and southeast on the Alice River are the Koko-Olkol and Koko-Gol from the upper Alice River occasionally wander into the region. East of these coastal tribes is a non-man's land with no native population and few cattle stations where wild pig abound. This uninhabited land and the Great Dividing Range acted as a considerable barrier to contact with the east coast aborigines even before the coming of the white man as it does today.

The Yir-Yoront are of good physique, tall stature, with much evidence of infusion with Melanesian stock in the distant past, but there is no evidence of miscegenation with Caucasians or Chinese in historic times. The members of this

tribe now intermarry frequently with the Koko-Bera, but marriage with the Kunjin is still rare—20 years ago it was almost unknown.

The Kunjin tribe is closely affiliated by marriage with the Koko-Olkol, Koko-Yan and Koko-Gol; a few of the latter tribe are now living at the mission.

There are 30 caste people at the mission besides the 350-400 full-blooded aborigines. Koko-Bera is used among the natives as a common language, but it has been debased by the younger people until it is now a mixture of Koko-Bera and English.

Edward River. Some 50 miles north of the Mitchell River Mission, between the Edward and the Holroyd Rivers, is to be found the most isolated of the Gulf Coast aboriginal settlements, the Edward River Mission. Here remnants of the Yir-Yoront (Koko-Manjoen), the Koko-Daiyuri (Koko-Taiyor), the Wik-Ngencherra and the Wik-Mungken have settled, and the groups live together with the least tribal disorganization of any of the settlements on the Gulf coast. The total population of this region is about 250 aborigines, all full-blooded, and of these 50-100 live a hunting, food-gathering life in the bush. The remainder spend most of their time about the mission. Native languages are still preserved. There is some passage back and forth to the Mitchell River Mission by a long 70 mile overland route which involves swimming the crocodile infested rivers, but this contact is infrequent.

Aurukun. The Aurukun mission natives number 500-550 today, and they include most of the disorganized remnants of the Wik-Mungken, Wik-Eppa, Wik-Ngartona and Wik-Ngencherra linguistic groups. For the past several decades intermarriage between these groups has been extensive, but there has been very little contact or intermarriage between these tribes, centred around Aurukun mission, and those around Edward River mission to the south, and only occasional intermarriage with Weipa mission natives to the north. No more than 150 of the approximately 500 aborigines belonging to these groups lead a nomadic hunting life in the bush today. These are now found on the Holroyd and Kendall Rivers.

Most remain at the mission station, except for occasional walkabouts.

The Wik-Mungken (Wik-Mongken) are the largest and most important tribe of those characterized by names formed with the word "Wik-," meaning "speech," which occupy a stretch of country along the Gulf of Carpentaria 30-50 miles wide through which flow the Watson, Archer, Kendall and Holroyd Rivers. In 1930, there were about 50-100 Wik-Mungken belonging to the Archer River region, including the Aurukun mission and those who worked outside of the Reserve, and about 200 on the Holroyd, Kendall and Edward Rivers. The population may have been three to four times as great in the past, but probably not in excess of 1,000. For a generation the Archer River Wik-Mungken have been largely sedentary at the mission station, while only a few still move to and fro between the mission and their hunting grounds. The smaller Wik-coastal tribes which separate the traditional Wik-Mungken lands from the coast number some 200 members. They include, from north to south, the Wik-Eppa, Wik-Tinda, Wik-Kalkin, (Wik-Alkan), Wik-Ngartona, (Wik-Natan) and Wik-Ngencherra (Wik-Natjerra). The Wik-Kalkin make the greatest contribution to the Aurukun populace of today, while the Wik-Tinda were almost extinct 20 years ago. On the coast north of the Archer River the Andjingit (almost extinct in 1933) and the N'Drangit are other tribes that have contributed somewhat to the current Aurukun people.

Weipa. A group of small tribes which the Wik-Mungken refer to as the Wik-Waiya (meaning "speech bad"), clustered about Albatross Bay at the mouths of the Mission, Hey, and Embley Rivers have mixed to form the present day populace of Weipa mission. These are the former Wimmarrango, Tani-kutti, Lainingitti, M-Berwum (Bywoom), N-Dwangit (Drag-nite), Linngitti, Aredinngit (Aritchenite) and Latumngit tribes. Other tribal names of the region are Yeemwoom, Tee-pani and Gott. There are only about 160 natives now in the Weipa mission village. The mission school has 40 children, some 30 of them boarding at the dormitory. Native languages

are rapidly disappearing, the younger children using mostly English. Since the expedition with the Flying Doctor Service in June, 1956, on which the blood specimens were collected, one of the authors (D. C. G.) has again visited the Gulf coast region with Flying Doctor Tim O'Leary, and found that extensive work on the vast bauxite resources at Weipa has begun. White working crews are settled near the mission and, shortly, large scale operations, including the opening of a seaport, will be in progress. Most of the young male adults of the mission are now employed as day labourers on this mining project and, although the native village remains a full-blooded aboriginal community, its complete disorganization seems imminent.

Here, as elsewhere on the coast, the variety of physical types among the full-blooded aborigines is striking. Some have features and hair characteristic of the aborigines of Central Australia, while others have distinctly Melanesian features, physique and hair.

Mapoon. Even before the 20th Century recruiters for Thursday Island pearling luggers found willing and skilled seamen in the Port Musgrave region tribes (the Ngammatta, Tjungundji, Yupungatti, Teyepathiggi, Athokurra and Oyonggo), and by 1890, when Nicholas Hey and J. G. Ward established the Mapoon mission on Cullen Point, the population already included many mixed bloods. Today tribal languages and identities have disappeared in the region, and most of the Mapoon natives are of mixed blood, while those few who are apparently full-blooded aborigines (and these only were used in this study) can no longer state their tribal affiliations. There are now some 300 natives, over half of them mixed-bloods, now living at Mapoon village. Ninety-one children attend the mission school. English is the only spoken language.

MATERIALS AND METHODS

Because of the nature of the pediatric and serological epidemiological problems for which the blood specimens were collected, the entire infant, child and adolescent populations

were chosen rather than the adult population, which is usually selected for blood group genetic study. Specimens were obtained from the majority of the population under 20 years of age at the Mitchell River, Edward River and Aurukun Mission regions and from a somewhat smaller proportion of the total child population at Weipa and Mapoon. From the total of over 500 blood specimens collected from "full-blooded" aboriginal children, 267 random samples were blood grouped. These comprised 100 specimens from each of the Mitchell River and Aurukun collections, 50 from the Edward River and 17 from Weipa and Mapoon.

Sterile blood samples (20-30 ml) were collected from the antecubital vein in older children, and from the femoral vein in infants and younger children, and were allowed to clot. The specimens, without preservative, were refrigerated a few hours after collection at about 4°C, until their arrival in Melbourne by air-freight. The serum samples were stored at -20°C, and red cell samples from the clots were prepared in glucose-citrate blood preservative, and stored at 4°C. The methods employed in testing the blood samples have been described by Simmons, Graydon, Semple and Taylor ('51).

RESULTS AND DISCUSSION

The A-B-O, M-N, Rh, Diego and Duffy blood groups and gene frequencies are presented in tables 1 to 4.

The A-B-O- blood groups. It was not unexpected that group B would be found in natives of the Cape York Peninsula, because this is an area in which contact with Melanesians and others is definitely known. What was surprising, however, was that 26% of the children sampled at the Mitchell River Mission were of group B, and this mission is the most southerly of the five missions within the Aboriginal Reserve. At Edward River Mission group B was 2%, while at Aurukun Mission there were 5% of group B. The numbers tested at Weipa and Mapoon total only 17, but two of 7 children at Mapoon were of group B.

It is generally accepted that unmixed Australian aborigines lack group B, and thousands of tests on selected aborigines

in both published and unpublished series support this view. In only three of the 20 A-B-O surveys prior to '40 listed by Birdsell and Boyd ('40) were examples of group B found, and these occurred at Barambah (now known as Cherbourg), South Queensland, and at Palm Island off the north Queensland coast. There is no doubt that these natives were of mixed blood as subsequent surveys at these places have detected group B only in individuals of mixed descent. Birdsell and Boyd indicated in one map an area of probable group B penetration from the north across the northern part of Australia from Western Australia to Queensland. Wilson, Graydon, Simmons and Bryce ('44) as the result of their surveys in Western Australia, the Northern Territory, Queensland, New South Wales and South Australia, considered that the major area of B penetration extended only from the Gulf of Carpentaria near the border of the Northern Territory and Queensland, to the coast of North Queensland in the east. Odd natives possessing group B have moved south far beyond the original projected areas of penetration, but this movement does not affect the present survey which was the first made in the Cape York Peninsula, and one which falls within the recognized area of B penetration.

A special analysis of the A-B-O groups in the Mitchell River families was made, because the high proportion of group B, and the absence of group AB, made us suspect that some unusual factor was affecting the blood group distribution. There were 26 group B children, and of these 13 were from 4 mothers, and 13 were from 13 mothers. The family distribution in the four families after additional tests were made was as follows:-

One family, 5 group B, one group O, and one group B not in the series.

One family, two group B.

One family, two group B and one group A₁.

One family, 4 group B, and one group A₁ not in the series.

In the remaining 13 families there were:-

Five children of group B without siblings.

Seven children of group B who had one sibling, and of these

siblings 4 were group 0 and one was group A_1 and in addition one of group B and one of group A_1B not in the series were found in later tests. One child of group B had 4 siblings, two of group 0 and two of A_1 were in the series.

The blood groups in the families with group B, and those without group B in the 100 sampled at Mitchell River, may be summarized as follows:

NUMBER OF CHILDREN OF GROUP B FAMILIES TESTED IN THE SERIES	O	A_1	B	A_1B
37	7	4	26	0
Four additional children of these families not in the series were later grouped as, one group A_1 , two group B, and one group A_1B .				
NUMBER OF CHILDREN FROM FAMILIES WITHOUT GROUP B	O	A_1	B	A_1B
63	49	14	0	0

An examination of the tribes in relation to those families with group B and those without B at Mitchell River, suggests that all three tribes possess group B in much the same amount. This would not be unexpected in view of the extensive intermarriage of these tribes in recent years.

On the basis of the proportion of groups A and B found in the series, the expected number of group AB would be less than three. The absence of group AB from the series is not a statistically significant deviation from this expectancy. That chance was responsible for this is evident from the finding of one group AB amongst the 4 tested in the follow up, which, because they were not among the 100 random samples tested, were not included in the series.

As was stated earlier the exceptionally high group B frequency occurred only amongst the natives of the Mitchell River Mission in the south. It is impossible at this stage without a knowledge of the genealogies of the natives concerned, to offer any explanation for this high B frequency in three tribes. It is recognized that one man of power, a tribal chief for

POPULATION	NO. TESTED	BLOOD GROUPS				GENE FREQUENCIES			
		O	A ₁	B	A ₁ B	A	B	O	
Mitchell River Mission	100	56	18	26	0	.10	.14	.76	
Edward River Mission	50	37	11	1	1	.13	.02	.85	
Aurukun Mission	100	89	6	5	0	.03	.03	.94	
Weipa Mission	10	6	4	0	0	—	—	—	
Mapoon Mission	7	2	3	2	0	—	—	—	
Totals	267	190 71.2%	42 15.7%	34 12.7%	1 .4%	.084	.068	.848	

TABLE 2

M-N types and gene frequencies

POPULATION	NO. TESTED	M-N TYPES				GENE FREQUENCIES		
		M	MN	N	n	m	n	
Mitchell River	100	10	45	45	.32(5)	.67(5)		
Edward River	50	6	22	22	.34	.66		
Aurukun	100	3	39	58	.22(5)	.77(5)		
Weipa	10	1	3	6	—	—		
Mapoon	7	1	3	3	—	—		
Totals	267	21 7.9%	112 41.9%	134 50.2%	.288	.712		

TABLE 3

Rh types and gene frequencies

POPULATION	NO. TESTED	Rh TYPES								GENE FREQUENCIES		
		Rh ₁ Rh ₁	Rh ₁ Rh ₂	Rh ₂	Rh ₁ Rh ₀	Rh ₂	Rh ₁ Rh ₂	Rh ₁ Rh ₀	Rh ₂ Rh ₀	R ¹	R ²	R ⁰
Mitchell River	100	62	12	1	11	14	0	0	.79	.06	.07	.08
Edward River	50	20	16	1	8	4	1	1	.66	.08	.20	.06
Aurukun	100	45	30	2	14	0	9	0	.67	.08	.25	—
Weipa	10	10	0	0	0	0	0	0	—	—	—	—
Mapoon	7	5	1	0	1	0	0	0	—	—	—	—
Totals	267	142 53.2%	59 22.1%	4 1.5%	34 12.7%	18 6.7%	10 3.7%	0	.727	.064	.163	.046

instance, may transmit an unusual blood group antigen to many offspring. Such a case was reported by Simmons, Graydon and Semple ('53) who found group B amongst the Polynesian people of Kapingamarangi. The genealogies provided at that time by Dr. K. P. Emory from Honolulu, showed that one white man by his marriage with a Kapinga woman, had produced many children of group B in a people who normally lacked group B.

In the present survey group B occurred in families presented by the mission staff as "pure-blooded" arborigines, so that the introduction of group B is not recent. Recent admixture is known to the mission people, and often by the na-

TABLE 4
Duffy (Fy^a) and Diego (Di^a) blood groups

POPULATION	Fy (a+)	Di (a+)
Mitchell River	14/14	0/14
Edward River	14/14	0/14
Aurukun	14/14	0/14
Weipa	4/4	0/4
Mapoon	4/4	0/4
Totals	50/50 100 %	0/50 0 %

tives themselves. Earlier in this paper when referring to natives at Mapoon, it was said that there was a large population of natives of mixed blood, and that admixture had taken place with Melanesians, Malays, Chinese, Polynesians and Whites. It was also said that Malay contacts on the western side of the Gulf of Carpentaria were known to have been considerable. Captain Matthew Flinders (1814) who reported hundreds of Malay fishing vessels there from Macassar as early as 1802, said that the Malay crews did not interfere with the Australian aborigines, who were not particularly friendly. Contacts with natives on the eastern side of the Gulf could not have been great, because of the more treacherous coast.

From the time of the Gold Rush there were a great many Chinese employed about Cooktown, and Chinese gardeners

ABORIGINAL MISSIONS ON THE GULF OF CARPENTARIA COAST OF CAPE YORK PENINSULA



Map of Cape York Peninsula.

and cooks were frequently employed on cattle stations. The possibility of Chinese contact half a century ago must be considered as a possible source of this B gene, however, there was nothing to suggest that any of the "pure-blooded" aborigines presented for sampling possessed any Chinese admixture. Further, Chinese were not known on the Gulf coast itself, but were mainly on inland cattle stations where Chinese-aboriginal crosses are evident. In the case of the Japanese, who might have introduced the B gene, their recruiting parties for Thursday Island pearling luggers concentrated their activities on the eastern coast of Cape York, and did not visit the Gulf coast.

A further influence which may have introduced group B to the native population of Queensland generally, but not to Cape York Peninsula, was the importation many years ago of Melanesian natives of the New Hebrides to work in the sugarcane fields. Remnants of these people mixed with Australian aborigines are still evident, particularly in southern Queensland and northern New South Wales. It is most unlikely that Cape York natives had any contact with the New Hebridean cane workers.

In referring earlier to the natives of the Mitchell River Mission we said—

"The Yir-Yoront are of good physique, tall stature, with much evidence of infusion with Melanesian stock in the distant past, but there is no evidence of miscegenation with Caucasians or Chinese in historic times."

Simmons, Graydon, Semple and Swindler ('56) have shown that the gene R^2 possessed by the Australian aborigines is also present in Melanesian natives of Daru Island, New Guinea, but has not been found elsewhere in Papua, New Guinea, New Britain or the Admiralty Islands. It would seem fair to say that the chief external influence on Australian aborigines of the Cape York Peninsula in past centuries, has undoubtedly been from New Guinea, due to the exchange of visits. It is possible that one man, or just a few men were re-

sponsible for the high group B frequency found in the Mitchell River Mission natives, and on the basis of physical characters observed, the influence was essentially Melanesian.

The calculated A-B-O gene frequencies are A .084, B .068 and O .848. The O is high as is usual with aborigines, the increase in B has been at the expense of the A . No example of subgroup A_2 was found in the series.

The M-N types. The M-N frequencies are m .288 and n .712. There is no evidence in the Mitchell River series of any special influence affecting the results, which are almost identical with those found at Edward River. The highest n .77(5) was found at Aurukun. M-N frequencies presented by Birdsell and Boyd ('40) for 730 Australian aborigines, by Wilson et al. ('44) for 649, by Simmons et al. ('54) for 165, and by Simmons et al. ('57) for 125, were respectively:

(730) m .178, n .822

(649) m .297, n .703

(165) m .255, n .745

(125) m .236, n .764

The M-N frequencies for Cape York aborigines are similar to those found for aborigines in other parts of Australia.

The Rh types. The calculated gene frequencies are: R^1 .727, R^2 .064, R^0 .163, R^z .046. Rh frequencies presented by Simmons and Graydon ('48) for 234 aborigines of which about one-half originated in Queensland, by Sanger, Walsh and Kay ('51) for 80 natives of Cherbourg and Woorabinda, Queensland, and 98 of Bathurst Island, Northern Territory, by Simmons et al. ('54) for 167 aborigines in the Northern Territory and South Australia, and by Simmons et al. ('57) for 105 natives of Haast's Bluff, Northern Territory, were respectively:

	R^1	R^2	R^0	R^z	r'
(234)	.564	.201	.085	.021	.129
(80)	.676	.114	.130	.080	—
(98)	.638	.077	.286	—	—
(167)	.541	.371	.072	.016	—
(105)	.560	.252	.119	.069	—

The raised R^1 .727 and the lowered R^2 in natives of the Cape York Peninsula are consistent with Melanesian influence. The natives of New Guinea possess the highest R^1 found in any people to date, a frequency as high as .945 for R^1 having been recorded. The A-B-O, M-N and Rh frequencies for Papua, New Guinea, Admiralty Island and New Britain have been tabulated by Simmons et al. ('56).

Rh variants. The following Rh variants were found:

Mitchell River Mission. Of the 100 samples tested two were "high-grade" $Rh_o(D^u)$ variants, and one was a "high-grade" $rh''(E)$ variant.

Edward River Mission. Of the 50 samples tested, three were "high-grade" $Rh_o(D^u)$ variants, one was a "high-grade" $rh'(C)$ variant, one was a "high-grade" $rh''(E)$ variant, and one was a "high-grade" $hr'(c)$ variant.

Aurukun Mission. Of the 100 samples tested two were "low-grade" $Rh_o(D^u)$ variants which were confirmed by the anti-globulin test, 8 were "high-grade" $Rh_o(D^u)$ variants, and 6 were "high-grade" $rh'(C)$ variants.

It is known that Rh variants occur in Australian aborigines and Melanesians particularly in New Britain, but no group of natives has previously been encountered by us in which such large numbers of variants have been detected, and with so many of the Rh antigens involved. It is thought that the observations are true, although the blood samples had been sent as clotted blood, and the cells which had subsequently been transferred to glucose-citrate preserving solution (Simmons, Graydon, Semple and Taylor ('51) were not fresh when tested, but were free from haemolysis. Subsequent tests with several of each of the respective antisera anti- $rh'(C)$, anti- $rh''(E)$ and anti- $hr'(c)$ strengthened the view that the weakly reacting cells were, in fact, variants.

There were 14 examples of Rh_1Rh_2 at the Mitchell River, and 9 examples of Rh_oRh_o at Aurukun, but they were not related to any particular tribe. One family possessed 5 examples of Rh_1Rh_2 , while there were two examples in each of two families, and 5 single examples in 5 families.

The Duffy (Fy^a) and Diego (Di^a) blood groups. A random lot of 50 blood samples was tested by the antiglobulin method for both the Duffy and Diego blood groups. All of the 50 were Fy(a+), and no example of the Di^a antigen was found. The Duffy results are consistent with those found in Australia and the Pacific peoples generally. In previous tests on 112 Australian aborigines at Haast's Bluff, Central Australia, the Diego antigen was not detected.

Preliminary tests for the Diego antigen in some Pacific peoples have been made and reported by Simmons ('57), and its apparent absence in the Australasian area and in eastern Polynesians has been briefly discussed by Simmons and Graydon ('57), and by Simmons et al. ('57) in relation to its presence in American Indians, and its apparent absence in Eskimos. It is considered that the Diego antigen may be proved of great anthropological importance when its presence or absence in various racial groups has been adequately investigated.

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spective Institutes especially from Miss V. Casey and Miss Lois Larkin.

SUMMARY

Blood samples from 267 Australian aboriginal children living in the Aboriginal Reserve of the Cape York Peninsula have been tested for the A-B-O, M-N, Rh, Duffy (Fy^a) and Diego (Di^a) blood groups. No previous blood group genetical survey has been done in this region.

The Cape York Peninsula falls within the area of recognized group B penetration in Australia, but the finding of 26% group B amongst the children of the Mitchell River Mission was unexpected. A special analysis of the families concerned is presented, together with tribal data for the natives of the five mission stations. The various influences which may have introduced group B are briefly discussed. It is thought that the major influence was Melanesian, and the calculated gene frequencies are not inconsistent with this belief. The admixture is not recent because the natives were presented by the mission staffs as "pure-blooded." Admixture with natives of New Guinea has probably taken place in past centuries by the interchange of visits, for the gene R^z common in Australian aborigines has been found in Melanesian people only at Daru Island off the coast of Papua, and this island was presumably a terminal point for such visits.

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A RE-EVALUATION OF ESTIMATION OF STATURE BASED ON MEASUREMENTS OF STATURE TAKEN DURING LIFE AND OF LONG BONES AFTER DEATH¹

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SEVEN FIGURES

It may be recalled that the first study (Trotter and Gleser, '52) followed World War II and was based chiefly on stature measurements of male military personnel taken at the time of induction and on long bone lengths of the same individuals taken at the time of repatriation of their skeletal remains.² The data from the military subjects were limited to American Whites and Negroes and, through official restriction, to a relatively small number of this available group. Nevertheless, the equations for estimation of stature from long bone lengths which resulted from the study were utilized by the American Graves Registration Service, Quartermaster Corps, Department of the Army, in the identification of American remains following the recent war in Korea. Presumably, more precise estimates of stature were derived from them than from other available equations or tables.

The present undertaking is a consequence of official recognition that the war in Korea provided again the unusual combination of data (taken before and after death of the same individual). From such combination may be expected greater precision in living stature estimates from long bones than when all measurements are taken either on the living or on

¹ This investigation was supported (in part) by the Department of the Army through its contract No. DA19-129-QM-562.

² Supplemental data based on the Terry Collection were included also but treated separately. All comparisons with the first study throughout this paper will be limited to the military data unless otherwise stated.

the dead. This study consists of validation and refinement of the equations for estimation of stature of American White and Negro males derived in the first study and of derivation of tentative equations for estimation of stature of American Mongoloid, Mexican, and Puerto Rican males.

MATERIAL AND METHODS

The data are all derived from American male military personnel in the Korean War (1950-'53). Stature measurements had been recorded in inches at the various stations at the time of induction into military service. "Directions for taking height" in the Mobilization Regulations, War Department, were reviewed for the first study; there is no evidence of change in the directions since that time. Long bone lengths were measured in centimeters by technicians in the processing laboratory in Japan according to methods described in the first study (*op. cit.*). In that study two lengths were considered for femur (maximum and bicondylar) and for tibia (maximum and ordinary). In the present study only the maximum length of each bone was analyzed, so the use of the subscript *m* to indicate the maximum length of each of these bones is not necessary. It should be noted, therefore, that the lengths of femur and tibia in the present study may be compared directly only with lengths indicated as Fem_m and Tib_m in the first study. The condition of the bones at the time of measurement varied from "dry" to "moist." The remains were not limited, as in the first study, to include only those whose identity had never been lost nor to American citizens who had been born in the United States.

The onerous task of selecting the records, sorting into racial groups, changing inches to centimeters, and of transcribing the data to IBM cards was carried out under the direction of Dr. Russell W. Newman, Quartermaster Research and Engineering Command, U. S. Army. During the course of the study he provided the IBM processing as requested. Grateful acknowledgment is made to him.

The distribution of subjects according to geographical location and racial origin is shown in table 1.

TABLE 1

Distribution of subjects according to geographical location and racial origin

	WHITE	NEGRO	MONGO- LOID	MEXICAN	PUERTO RICAN	TOTAL
U.S.A.	4650	573	25	112	14	5374
Alaska	1		1			2
Hawaii	12		58		3	73
Puerto Rico		3			47	50
Other	9 ¹	1 ²	8 ³			18
Total	4672	577	92 ⁴	112	64	5517

¹ Four from Canada, one from Canal Zone, two from Ireland, one from Belgium, one from Poland.

² One from British West Indies.

³ Eight from Philippine Islands.

⁴ Consists of 23 Japanese, 22 American Indians, 20 Filipinos, 9 Hawaiians, two Chinese, two Samoans, one Malayan and 13 who are mixtures of White-Mongoloid and Mongoloid sub-groups.

Statistical analyses of the data are based on regression equations as before. Unlike the earlier study, however, the lengths of the right and left bones of a given pair are not averaged, but, rather, bones of the two sides are considered separately. This departure from the precedent established in 1952 simplified the transcription of data to IBM cards, an understandable maneuver in view of the enormity of the task. Furthermore, since the presence of all long bones in a given remains was not established as essential for analysis (as in the first study), it was possible to include many more subjects. The separate consideration of each right and left bone accounts for the disparity, both between the number of right and left bones of any given pair, and, also, between these numbers for the different bones and the total number of subjects. The individual remains which presented all long limb bones of the right side, all of the left side and all of both sides are shown in per cent of the total number of each group as follows:

LONG LIMB BONES	WHITE	NEGRO	MONGO- LOID	MEXICAN	PUERTO RICAN
All of right (%)	27.0	31.7	39.1	23.2	34.4
All of left (%)	27.1	33.1	34.8	23.2	32.8
All of both (%)	21.4	25.6	20.7	12.5	21.9
No. of remains	4672	577	92	112	64

Errors in such an involved undertaking are bound to be multiple since they can arise from so many possible sources: in the large number of individuals measuring not only stature but also bone lengths; in the recording of measurements; in converting inches to centimeters; and in transcribing data to IBM cards. It is likely that errors are random and thus have not biased the averages of stature and bone lengths; they will, however, tend to increase the standard errors of estimate of stature from long bone lengths. This is not wholly undesirable, since the increased standard errors of estimate will provide more nearly the predictive accuracy which can be expected in practice, since the conditions under which these data were obtained are those usually met in applying formulae.

RESULTS AND DISCUSSION

The mean stature of each of the five racial groups is presented according to age in table 2. Any given year includes the period from one birthday to the next, as in the first study.

The mean stature of the total White series (173.95 cm) differs from that of the first study by only -0.28 cm, whereas the present series of American Negroes has a mean stature (173.43 cm) which exceeds the mean stature of the earlier comparable series by 1.29 cm. Neither of these differences is statistically significant.³ It is interesting that in both studies the Whites are taller than the Negroes, although in the present study the difference is not statistically significant as it was in the previous study. The mean statures of the remaining three groups are shorter, 168.73 cm and 168.65 cm for the Mongoloid and Mexican, respectively, and 166.64 cm for the Puerto Rican group.

As in the first study, measurements of the Whites and Negroes who were less than 18 years of age at the time of induction (when stature was measured) are excluded from analyses providing preliminary regression equations for estimation of stature. In both these groups of the present study

³ A difference is considered to be statistically significant in this study when $P \leq .05$.

the 17 year olds are significantly shorter than the 18 year olds. The 17 year olds in the other three racial groups are also excluded from the correlation computations, even though their mean statures do not differ significantly from those of the 18 year olds. In table 3 are presented the means and standard

TABLE 2
Mean stature (cm) of subjects according to race and age (years)

AGE	NO.	STATURE	AGE	NO.	STATURE	AGE	NO.	STATURE
White			Negro			Mongoloid		
17	1224	172.36	17	108	171.87	17	6	170.50
18	793	173.57	18	98	174.33	18	18	167.11
19	479	174.22	19	75	173.17	19	6	169.33
20	389	173.79	20	39	173.49	20	12	168.25
21	342	175.09	21	60	173.25	21	8	171.75
22	288	174.92	22	44	174.39	22	3	169.33
23	190	174.97	23	28	172.14	23	9	167.33
24	172	175.67	24	20	173.40	24	9	172.67
25	145	176.35	25	26	174.19	25	6	165.00
26	125	174.74	26-30	48	174.27	26-30	7	170.43
27	89	175.68	31-42	31	174.77	31-45	8	166.50
28	80	175.62	Total 577 173.43			Total 92 168.73		
29	51	176.16	Mexican			Puerto Rican		
30	54	174.04	17	39	168.64	17	4	167.75
31	54	175.33	18	21	168.71	18	6	168.00
32	44	174.41	19	16	169.88	19	6	163.83
33	36	175.36	20	10	167.00	20	5	166.60
34	24	174.25	21-25	20	168.30	21-24	21	165.24
35-39	69	174.61	26-34	6	169.17	25-29	16	168.62
40-46	24	172.04	Total 112 168.65			30-35	6	167.00
Total 4672 173.95						Total 64 166.64		

deviations of stature and of bone lengths according to side for each of the five groups, the correlation coefficients of bone length with stature, and equations for estimation of stature with standard errors. All the correlation coefficients of bone length with stature obtained from the White sample of the present study are lower than the corresponding coefficients of the previous study. The correlation coefficients for the

TABLE 3

Means and standard deviations (S.D.) of statures and bone lengths, correlation coefficients (r) of bone lengths with stature, and equations for estimation of stature (with standard errors) according to side and racial group of those 18 years and older.

BONE AND SIDE	CASES	STATURE		BONE LENGTH		CORRELATION COEFFICIENT	ESTIMATION EQUATION
		Mean	S.D.	Mean	S.D.		
	no.	cm		cm		r	cm
White							
Hum R	2817	174.591	6.738	33.641	1.708	.730	$2.88 H_R + 77.70 \pm 4.61$
Hum L	2817	174.467	6.609	33.562	1.663	.727	$2.89 H_L + 77.47 \pm 4.54$
Rad R	2673	174.534	6.697	25.306	1.274	.718	$3.77 R_R + 79.13 \pm 4.66$
Rad L	2641	174.421	6.615	25.147	1.277	.720	$3.73 R_L + 80.62 \pm 4.59$
Ulna R	2652	174.502	6.684	27.174	1.321	.710	$3.59 U_R + 76.95 \pm 4.71$
Ulna L	2638	174.443	6.586	27.005	1.303	.720	$3.64 U_L + 76.14 \pm 4.57$
Fem R	2327	174.324	6.740	47.077	2.382	.795	$2.25 F_R + 68.40 \pm 4.04$
Fem L	2345	174.269	6.691	47.150	2.345	.805	$2.30 F_L + 65.82 \pm 3.97$
Tib R	2483	174.469	6.664	38.429	2.226	.803	$2.40 T_R + 82.24 \pm 3.97$
Tib L	2482	174.433	6.668	38.457	2.214	.806	$2.43 T_L + 80.98 \pm 3.95$
Fib R	2207	174.451	6.589	38.258	2.084	.811	$2.57 Fi_R + 76.13 \pm 3.80$
Fib L	2217	174.509	6.556	38.276	2.058	.812	$2.59 Fi_L + 75.37 \pm 3.83$
Negro							
Hum R	378	173.656	6.570	34.076	1.740	.762	$2.88 H_R + 75.52 \pm 4.26$
Hum L	385	173.579	6.542	34.075	1.736	.766	$2.89 H_L + 75.10 \pm 4.21$
Rad R	364	173.640	6.666	26.651	1.459	.717	$3.28 R_R + 86.22 \pm 4.65$
Rad L	361	173.734	6.709	26.518	1.474	.739	$3.36 R_L + 84.63 \pm 4.50$
Ulna R	368	173.633	6.661	28.503	1.498	.704	$3.13 U_R + 84.42 \pm 4.73$
Ulna L	348	173.724	6.823	28.315	1.492	.717	$3.28 U_L + 80.85 \pm 4.76$
Fem R	343	173.591	6.447	48.220	2.511	.805	$2.07 F_R + 73.78 \pm 3.83$
Fem L	338	173.740	6.756	48.388	2.552	.807	$2.14 F_L + 70.19 \pm 3.99$
Tib R	346	173.645	6.420	40.337	2.323	.797	$2.20 T_R + 84.90 \pm 3.88$
Tib L	342	173.716	6.651	40.318	2.426	.794	$2.18 T_L + 85.82 \pm 4.04$
Fib R	301	173.754	6.533	40.029	2.183	.795	$2.38 Fi_R + 78.48 \pm 3.96$
Fib L	306	173.542	6.580	39.968	2.229	.785	$2.29 Fi_L + 82.02 \pm 4.08$
Mongoloid							
Hum R	74	168.257	6.599	31.768	1.857	.756	$2.69 H_R + 82.80 \pm 4.32$
Hum L	65	168.338	6.462	31.742	1.836	.762	$2.68 H_L + 83.27 \pm 4.18$
Rad R	68	168.588	7.090	24.547	1.497	.756	$3.58 R_R + 80.71 \pm 4.64$
Rad L	67	168.701	6.850	24.303	1.460	.747	$3.51 R_L + 83.40 \pm 4.55$

TABLE 3 (continued)

BONE AND SIDE	CASES	STATURE		BONE LENGTH		CORRELATION COEFFICIENT	ESTIMATION EQUATION
		Mean	S.D.	Mean	S.D.		
	<i>no.</i>	<i>cm</i>		<i>cm</i>		<i>r</i>	<i>cm</i>
Ulna R	65	168.077	7.235	26.251	1.535	.743	3.50 U _R + 76.07 ± 4.84
Ulna L	65	169.231	7.029	26.126	1.560	.769	3.46 U _L + 78.84 ± 4.49
Fem R	67	167.836	6.560	44.246	2.479	.802	2.12 F _R + 74.03 ± 3.92
Fem L	60	168.450	6.523	44.640	2.476	.827	2.18 F _L + 71.11 ± 3.67
Fib R	68	167.573	6.011	36.038	2.092	.840	2.42 T _R + 80.36 ± 3.26
Fib L	67	168.687	6.440	36.503	2.349	.861	2.36 T _L + 82.54 ± 3.28
Fib R	61	167.492	6.088	36.146	2.170	.851	2.39 Fi _R + 81.10 ± 3.20
Fib L	62	167.597	6.359	36.340	2.273	.857	2.40 Fi _L + 80.38 ± 3.28
Mexican							
Hum R	58	168.534	6.941	32.450	1.801	.786	3.01 H _R + 70.40 ± 4.29
Hum L	63	168.302	6.256	32.262	1.639	.741	2.82 H _L + 77.32 ± 4.20
Rad R	56	168.321	6.302	24.730	1.266	.761	3.79 R _R + 74.59 ± 4.09
Rad L	58	168.345	5.915	24.634	1.320	.736	3.30 R _L + 87.05 ± 4.00
Ulna R	57	168.860	6.458	26.682	1.344	.795	3.82 U _R + 67.67 ± 3.92
Ulna L	57	168.386	6.020	26.340	1.313	.719	3.30 U _L + 81.46 ± 4.18
Fem R	50	168.620	6.375	45.138	2.316	.874	2.41 F _R + 59.84 ± 3.10
Fem L	57	169.000	6.759	45.596	2.474	.905	2.47 F _L + 57.51 ± 2.88
Fib R	51	168.882	6.489	37.300	2.356	.833	2.29 T _R + 83.46 ± 3.59
Fib L	52	168.846	6.996	37.487	2.401	.832	2.42 T _L + 78.13 ± 3.88
Fib R	52	168.414	6.637	37.154	2.221	.856	2.56 Fi _R + 73.30 ± 3.32
Fib L	45	168.689	6.425	37.342	2.150	.815	2.44 Fi _L + 77.58 ± 3.72
Puerto Rican							
Hum R	49	166.592	5.379	31.894	1.450	.660	2.45 H _R + 88.45 ± 3.96
Hum L	44	166.205	5.430	31.909	1.450	.744	2.79 H _L + 77.18 ± 3.63
Rad R	44	166.409	5.589	24.584	1.203	.698	3.24 R _R + 86.76 ± 4.00
Rad L	44	166.614	5.836	24.450	1.328	.759	3.33 R _L + 85.20 ± 3.80
Ulna R	40	166.775	5.690	26.422	1.293	.707	3.11 U _R + 84.60 ± 4.02
Ulna L	43	166.977	5.908	26.260	1.298	.764	3.48 U _L + 75.59 ± 3.81
Fem R	40	166.400	5.499	44.758	2.150	.816	2.09 F _R + 72.86 ± 3.18
Fem L	44	166.932	5.524	44.820	2.136	.816	2.11 F _L + 72.36 ± 3.19
Fib R	43	166.628	5.456	37.142	2.000	.750	2.05 T _R + 90.49 ± 3.61
Fib L	42	166.762	5.694	37.024	2.174	.744	1.95 T _L + 94.57 ± 3.80
Fib R	41	167.122	5.478	36.956	2.021	.772	2.09 Fi _R + 89.88 ± 3.48
Fib L	42	166.905	5.838	36.867	2.051	.760	2.16 Fi _L + 87.27 ± 3.79

present Negro sample are approximately the same as those obtained for the military Negroes in the first study with the possible exception of those involving humerus, femur and fibula. For these bones the present coefficients are somewhat higher (but not significantly so) than in the first study. All the correlation coefficients are slightly lower than those obtained in the first study for the Negro series of the Terry Collection. Further comparison between the first and present studies will follow.

The matrices of intercorrelations of lengths of long bones with each other and with stature according to side for the White and Negro series are presented in table 4. (Correlations between right and left bones are not available since the bones of the two sides were considered as separate samples.) The means and standard deviations of bone lengths and stature and the correlation coefficients of bone lengths with stature for these samples are also presented. It may be noted that little more than one-fourth of the total number of either racial group had a complete set of right or of left bones (see p. 81). Nevertheless, for the White sample, the correlation coefficients between stature and long bone lengths differ only slightly from those which were obtained from utilizing measurements of all *available* long bones (table 3). This illustrates the stability of such statistics for large samples and the fact that when sufficiently large samples are present the subset of cases with complete data is adequate and representative of the total sample. With the substantially smaller number of cases available in the Negro series, some differences between the correlation coefficients are noted, for example, the correlation coefficient of length of right humerus with stature (.705) in the smaller group (183 individuals) as compared to the coefficient (.762) in the total group (378 individuals).

The intercorrelations of long bones for the Mongoloid, Mexican and Puerto Rican groups were obtained but are not presented, since the samples are too small to be representative.

TABLE 4

Intercorrelations of lengths of long bones with each other and with stature according to side of the White and Negro series

	MEAN	S.D.	HUM	RAD	ULNA	FEM	TIB	FIB	STATURE
	cm	cm							
White ¹ R = 1261									
L = 1265									
Hum R	33.599	1.722		.836	.803	.838	.813	.822	.733
Hum L	33.529	1.639		.830	.797	.829	.807	.807	.732
Rad R	25.245	1.286	.836		.961	.803	.847	.858	.731
Rad L	25.140	1.278	.830		.961	.795	.842	.838	.715
Ulna R	27.131	1.320	.803	.961		.789	.835	.850	.730
Ulna L	27.013	1.296	.797	.961		.781	.825	.834	.715
Fem R	47.042	2.379	.838	.803	.789		.889	.873	.803
Fem L	47.170	2.301	.829	.795	.781		.884	.869	.805
Tib R	38.387	2.223	.813	.847	.835	.889		.967	.817
Tib L	38.417	2.173	.807	.842	.825	.884		.967	.803
Fib R	38.192	2.100	.822	.858	.850	.873	.967		.821
Fib L	38.247	2.051	.807	.838	.834	.869	.967		.810
Stature ² R	174.413	6.670							
Stature ² L	174.394	6.550							
Negro ¹ R = 183									
L = 191									
Hum R	33.913	1.620		.824	.796	.799	.797	.805	.705
Hum L	34.061	1.674		.837	.823	.840	.833	.828	.760
Rad R	26.589	1.458	.824		.972	.721	.777	.805	.706
Rad L	26.489	1.430	.837		.967	.804	.861	.868	.737
Ulna R	28.447	1.479	.796	.972		.700	.763	.791	.680
Ulna L	28.283	1.440	.823	.967		.796	.849	.853	.729
Fem R	48.109	2.456	.799	.721	.700		.863	.840	.807
Fem L	48.410	2.482	.840	.804	.796		.873	.843	.801
Tib R	40.200	2.303	.797	.777	.763	.863		.958	.780
Tib L	40.322	2.313	.833	.861	.849	.873		.967	.783
Fib R	39.832	2.184	.805	.805	.791	.840	.958		.781
Fib L	39.959	2.160	.828	.868	.853	.843	.967		.782
Stature ² R	173.240	6.250							
Stature ² L	173.864	6.651							

¹ Number of individuals with all right bones or all left bones present.

² Of those individuals whose right bones provided data and whose left bones provided data.

*Comparison of data of White and Negro series with
data of the first study*

The data presented for White males in table 4 may be compared directly with the corresponding data of the World War II sample (*op. cit.*, table 3, p. 475). The intercorrelations among the bones are practically identical in both studies with the exception of those involving the right radius which are slightly higher in the present study. To simplify comparison further, the means of stature and bone lengths and the correlations of bone lengths with stature obtained in the two studies are presented together in table 5. The significance ratios (*t*) for the differences between statistics of the two samples are included, also. To test differences in correlation the coefficients were transformed to Fisher's *z* (Weatherburn, '46) and significance ratios for the difference in *z*-values computed. The standard deviations of the distribution of stature and bone lengths are shown in this table, but the significance ratios for the differences are omitted since it was found that none of them even approached significance.

From table 5 it may be seen that the mean statures of the two series (18 years and over) differ by only 0.5 cm, the present series being the taller. Similarly, the mean bone lengths, with the exception of tibia, are approximately the same. However, the mean lengths of both the right and left tibia obtained in the present study are very significantly greater than those obtained in the previous study ($P < .001$). This difference is further emphasized by the fact that the tibia is longer on the average than the fibula, whereas in the previous study the reverse relationship was found. Possibly this difference between the two studies may be accounted for by different technicians measuring the maximum length of the tibia (from the end of malleolus to the most prominent part of the lateral half of the lateral condyle) which, of all the long limb bone lengths, is the most difficult to reproduce.

The correlation coefficients between stature and bone lengths obtained in the present study, with the exception of those for

TABLE 5

Comparison between statistics of American White males in World War II and Korean War series (18 years of age and over): means and standard deviations of stature (cm) and of long bone lengths (cm); correlation coefficients of bone lengths with stature; and significance ratios (t) for differences between the means and between the correlation coefficients.

	MEAN		t	STANDARD DEVIATION		CORRELATION WITH STATURE		t
	World War II	Korean War		World War II	Korean War	World War II	Korean War	
Right	N = 545	N = 1261						
Stature	173.899	174.413	1.71	6.626	6.670			
Humerus	33.640	33.599	.47	1.691	1.722	.783	.733	2.30 ¹
Radius	25.243	25.245	.03	1.338	1.286	.720	.731	.45
Ulna	27.131	27.131	.00	1.302	1.320	.751	.730	.90
Femur	47.232	47.042	1.57	2.358	2.379	.869	.803	4.32 ³
Tibia	37.799	38.387	5.20 ³	2.186	2.223	.859	.817	2.74 ²
Fibula	38.118	38.192	.69	2.074	2.100	.864	.821	2.74 ²
Left	N = 545	N = 1265						
Stature	173.899	174.394	1.46	6.626	6.550			
Humerus	33.595	33.529	.78	1.672	1.639	.788	.732	2.59 ¹
Radius	25.058	25.140	1.26	1.271	1.278	.764	.715	2.12 ¹
Ulna	26.938	27.013	1.14	1.285	1.296	.747	.715	1.34
Femur	47.290	47.170	1.00	2.357	2.301	.857	.805	3.29 ³
Tibia	37.854	38.417	5.03 ³	2.187	2.173	.865	.803	4.01 ³
Fibula	38.153	38.247	.88	2.107	2.051	.861	.810	3.31 ³

¹ P < .05.² P < .01.³ P < .001.

the right radius and the right and left ulnae, are all significantly smaller than those obtained in the first study (table 5). The probability that these differences arose by chance is less than .001 for each of the lower limb bones except for right tibia and fibula in which it is less than .01. Nor can these differences be attributed to a difference in range of values since significant differences were not found between the standard deviations of stature or of bone lengths. The result is that the standard errors of estimate of equations derived from the present series are significantly larger than of the first series and, thus, stature is not predicted with as much precision. As mentioned previously, variation from moist to dry among the bones, slight differences in technique of measuring the bones among the technicians, and errors incurred in handling such a large mass of data would lead to a decrease in predictive efficiency. The greatest contributing factor, however, may be that a change in stature-long bone length relationship is occurring in the American White male population (see below, p. 101).

The data of the Negro series in the present and previous studies are not directly comparable since the lengths of paired bones were averaged in the first study and are considered separately in the present study. However, in order to obtain some comparison between the two Negro series, the mean statures and bone lengths with standard deviations of both the World War II and Korean War series are presented in table 6; also, the correlation coefficients between stature and bone lengths using all available bones are listed for both series. It may be noted again that the Negro series of the Korean War is somewhat taller than the Negro series of World War II, but the difference is not statistically significant.^{3,4} Likewise, the tibia of the Negro group of the Korean War is

³ See footnote 3, page 82.

⁴ That both the White and Negro groups (18 years of age and over) of the Korean War series are taller than the corresponding groups of the World War II series (even though not significantly so) is not surprising considering the findings in an earlier study of trends in stature of American Whites and Negroes (Trotter and Gleaser, '51b).

TABLE 6

Comparison of statistics of American Negro males in World War II and Korean War series¹; means and standard deviations of stature (cm) and long bone lengths (cm); correlation coefficients (*r*) between bone lengths and stature

	MEAN			STANDARD DEVIATION				CORRELATION WITH STATURE			
	World War II		Korean War	World War II		Korean War		World War II ²		Korean War ³	
	N = 54			Right N = 183	Left N = 191	Right	Left			Right	Left
Stature	172.111			173.240	173.864			6.139		6.250	6.651
Humerus	33.793			33.915	34.061			1.337		1.620	1.674
Radius	26.568			26.589	26.489			1.240		1.458	1.430
Ulna	28.509			28.447	28.283			1.323		1.479	1.440
Femur	48.337			48.109	48.410			2.256		2.456	2.482
Tibia	39.554			40.200	40.322			2.298		2.303	2.313
Fibula	39.763			39.832	39.959			2.295		2.184	2.160
										.766	.795
										.805	.807
										.803	.797
										.766	.785

¹ The data pertaining to bones of right and left sides of World War II sample were averaged, but of Korean War sample were analyzed separately.

² Based on all subjects with both bones of any given pair available (*op. cit.*, table 7, p. 481).

³ Based on all subjects with either right or left bone available.

longer than of the World War II group, but the difference is not statistically significant as it is for the tibiae of the two White series. The only significant difference between the two Negro series is in the standard deviations of humerus; they are larger in the Korean War group, and evidently this increased spread accounts for the somewhat higher correlation coefficients between humerus (right and left) and stature in the Korean War series than in the World War II series. However, none of the correlation coefficients between bone lengths and stature differ significantly in the two series.

Comparison of regression equations of White and Negro series of first and second studies

It is of interest to test the validity of the appropriate regression equations for estimation of stature obtained in the first study by applying them to the present series of White and Negro males. This test involves, essentially, a comparison of the regression equations obtained for each racial group in the two studies. Unfortunately, a statistical comparison of the regression coefficients for the White series is not possible, because the standard errors of estimate of the two series are significantly different. However, the question of practical importance is: How well do the appropriate equations of the first study fit the present series when compared with the equations of best fit derived from the present series? This is difficult to ascertain from inspection of the equations, particularly since the interest lies in comparing the estimated statures only within the range in which given bone lengths actually occur. Therefore, in order to make the comparison, the equations for estimation of stature derived from right and left bone lengths of the present series were combined,⁵ and the resultant equations are plotted with the equations obtained from the World War II series (figs. 1 and 2).

⁵ The equations for stature estimation from right and left bones of a pair were combined by determining the average slope of the two equations and passing a line with this slope through the average of the mean statures and the mean bone lengths of the two samples.

It is evident in figure 1 that the equations for the two series of White males give nearly equivalent results. The equations for radius and ulna are practically identical. Those for humerus, femur and fibula intersect near the mean and diverge slightly at either end in such a manner that the World War II equations yield estimations of slightly shorter statures from bones of short lengths and slightly taller statures from bones of long lengths than do the Korean War equations. This difference is expected since the correlation coefficients in the first study are higher than in the second and result in steeper regression lines. The effect is somewhat greater precision in estimated statures at the extremes of the range in the first study, whereas estimated statures based on the data of the present study are somewhat closer to the mean of the series.

Comparison of the equations relating stature to length of tibia shows a somewhat different phenomenon. The lines (fig. 1) are separate, although not parallel, throughout the range with the greatest difference (approximately 2 cm in stature) occurring for long lengths of tibia. This finding is consistent with that noted above, viz., that the average length of tibia in the present series is significantly longer than in the World War II series, whereas the average statures do not differ significantly. Thus, a tibia of any given length *throughout* the range tends to be associated with a *shorter* stature in the present White series than in the previous series. Such a difference could result from either a change in the stature-tibia relationship (i.e., the tibia is actually longer relative to stature and, also, to lengths of other long limb bones in White males of the present series than of the World War II series) or from variation in the technique of measuring the tibia. The latter explanation seems more likely since a corresponding difference is not found in the length of the companion bone, the fibula. In general, it appears that estimates of stature of White males based on equations derived from the World War II series may be made for the Korean War series of 18 years of age and over with approximately the same precision as esti-

mates based on equations derived from the Korean War series itself.

In comparing the prediction equations derived from the Negro series of World War II and the present study, it must be borne in mind that the former series was quite small and

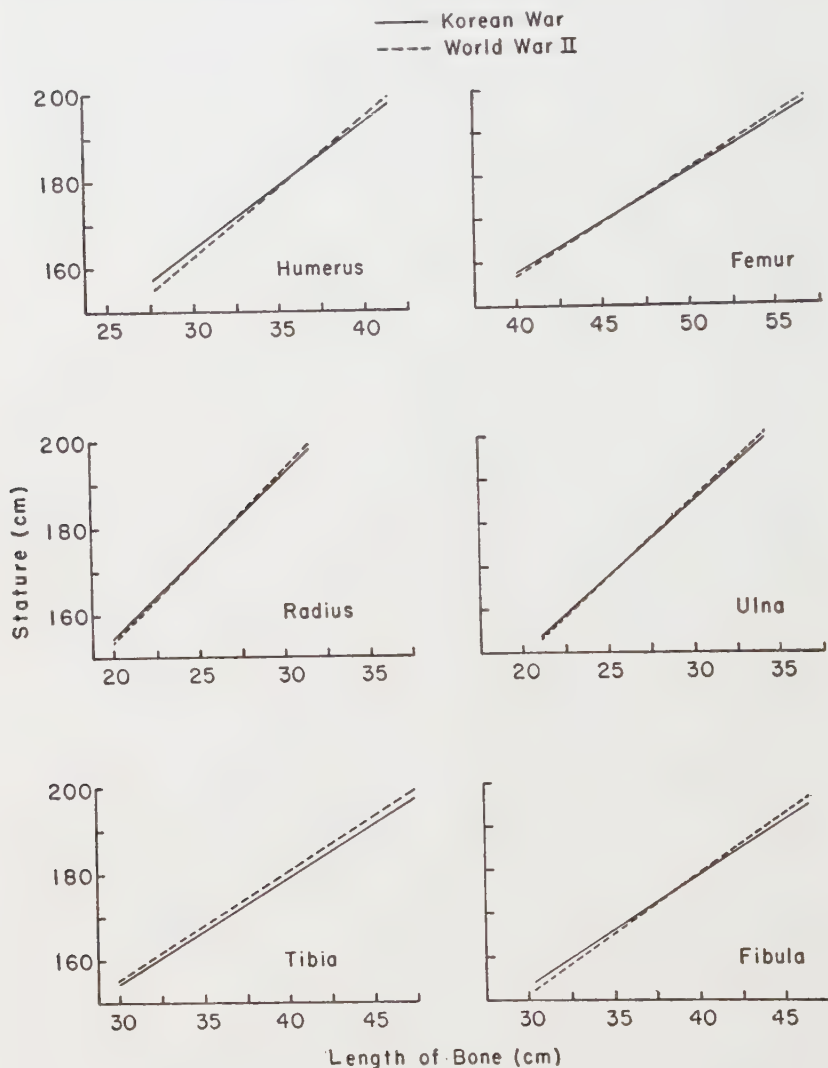


Fig. 1 Comparison of estimates of stature of White males of Korean War and World War II series according to length of long bones.

consequently the equations derived therefrom were subject to considerable sampling error. Thus, somewhat larger differences can be expected than between the White series of the two studies. The standard errors of estimate of stature from each long bone for the two Negro series do not differ more than would be expected by chance. It is evident that the slopes of the regression lines (fig. 2) are very similar, the greatest difference occurring for the humerus and fibula. For the humerus the prediction equation of stature derived from the Korean War series has a somewhat less steep slope than that from the World War II series, resulting in taller estimates of stature from short humeri and shorter estimates of stature from long humeri than the corresponding estimates obtained from World War II equations; the reverse relationship between the two series is found for the fibula. However, using a method suggested by Gulliksen and Wilks ('50) the difference in slopes was tested for significance and was found to be no greater than might be expected by chance. The regression lines in figure 2 for tibia demonstrate the same tendency that is found in the two White series for this bone, viz., that a given length of tibia tends to be associated with a shorter stature in the present series than in the previous series, although the difference is only approximately 0.7 cm and not statistically significant. The equations for radius, ulna and femur derived from the Korean War Negro series yield a somewhat taller stature estimate for any given bone length throughout the range than do the corresponding equations from the World War II series. The differences in these estimated statures average approximately 1.2 cm for the radius, 1.7 cm for the ulna, and 1.4 cm for the femur and are significant at the .05 level for both the ulna and femur. The finding of a significant difference between stature estimates from the ulna in the two samples, accompanied by a corresponding difference from the radius, although of smaller magnitude, indicates slightly shorter forearms relative to stature in the present generation of American Negro males than in the generation involved in World War II. This might imply an actual change in body

proportions of the Negro; on the other hand, it might indicate merely a sampling difference with a greater degree of racial mixture in the present series than in the former. It is unlikely that the explanation lies in measuring techniques, since a corresponding difference was not found in the two White series.

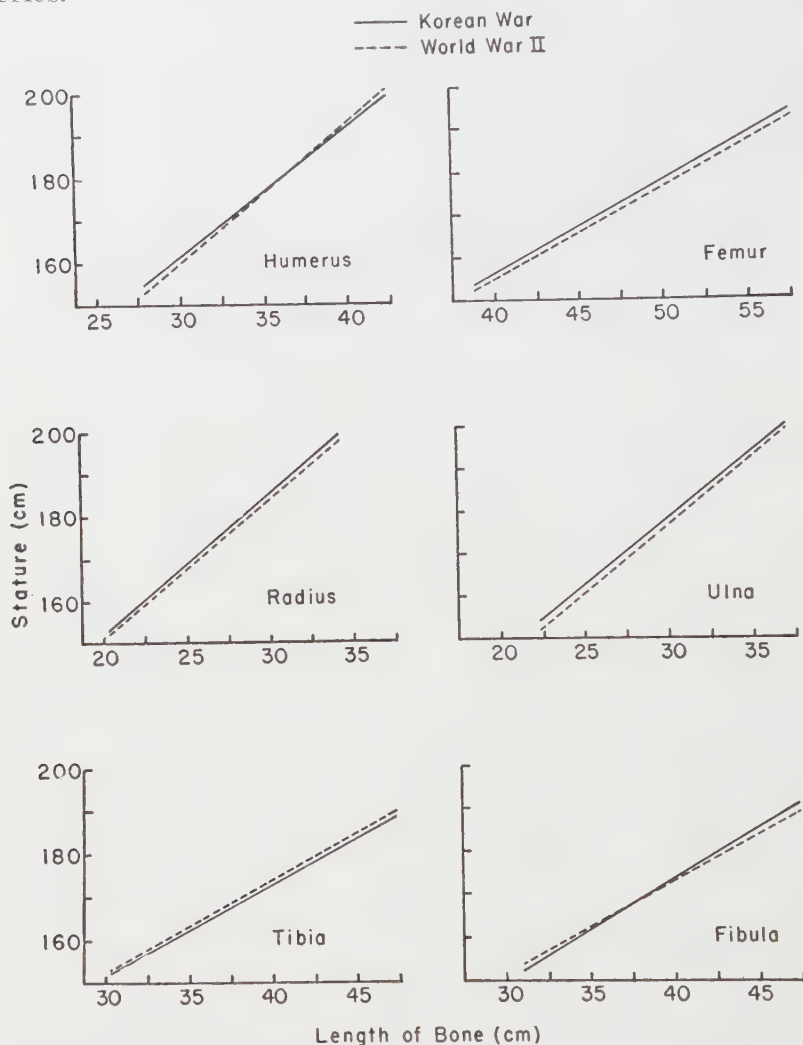


Fig. 2 Comparison of estimates of stature of Negro males of Korean War and World War II series according to length of long bones.

The suggestion of a change in the relationship of femur length to stature between the Negroes of the first and second studies is also of interest. If this is true, a similar change may be taking place in American Whites, since as mentioned above, the White male of the Korean War series is taller on the average than of the World War II series, even though the Korean War series has a slightly shorter femur. Before it may be concluded that a change in this relationship has actually occurred, the possibility that this finding may be due to variation in the method of measuring the maximum length of the femur would need to be eliminated. Since the prediction equations for Negroes are based on a considerably larger series in this study than in the previous one and the standard errors of estimate are no larger, it is likely that the Korean War series is more representative than the World War II series of the relationship between stature and long bone lengths in the American Negro population.

*Multiple regression equations for White and
Negro series*

Multiple regression equations for estimation of stature were computed using lengths of two or more bones in combination for the White and Negro series and are presented in table 7. Included in the table also are regression equations involving the sum of the lengths of humerus and radius or ulna, and the sum of femur and tibia or fibula. For each racial group the right and left bone lengths were treated separately. Only those cases were used for which either all right or all left bone measurements were available. As in the first study, the multiple regression equations yield only a small increase in precision of stature estimates over those obtained from equations which involved either the femur, tibia, or fibula alone. The contributions of the humerus, radius, and ulna are negligible, with the possible exception of the humerus in the Negro series. Furthermore, a comparison of the equations obtained for right and left bones provides additional evidence

TABLE 7

Multiple regression equations for estimation of stature (cm) (with standard errors) and coefficients of multiple correlation (R) with long bone lengths, and regression equations and coefficients of correlation (r) with sums of selected long bone lengths for White and Negro males according to side.

	RIGHT		LEFT	
	R	r	R	r
White				
.30 Hum + .22 Rad + .88 Fem + 1.32 Tib + 66.71 ± 3.66	.836		.45 Hum + .05 Rad + 1.06 Fem + 1.13 Tib + 64.64 ± 3.71	.831
.16 Hum + .22 Ulna + .93 Fem + 1.46 Fib + 63.56 ± 3.61	.841		.32 Hum + .15 Ulna + 1.04 Fem + 1.29 Fib + 61.22 ± 3.65	.837
1.77 (Hum + Rad) + 70.26 ± 4.31		.763	1.77 (Hum + Rad) + 69.96 ± 4.28	
1.78 (Hum + Ulna) + 66.31 ± 4.26		.770	1.80 (Hum + Ulna) + 65.42 ± 4.23	
1.03 Fem + 1.48 Tib + 69.15 ± 3.69	.834		1.24 Fem + 1.26 Tib + 67.50 ± 3.74	.828
1.02 Fem + 1.60 Fib + 65.32 ± 3.62	.840		1.17 Fem + 1.44 Fib + 64.13 ± 3.67	.835
1.24 (Fem + Tib) + 68.48 ± 3.69		.833	1.25 (Fem + Tib) + 67.41 ± 3.74	.828
1.29 (Fem + Fib) + 64.46 ± 3.64		.838	1.30 (Fem + Fib) + 63.35 ± 3.67	.835
Negro				
-.16 Hum + .90 Rad + 1.28 Fem + .59 Tib + 69.44 ± 3.47	.832		.70 Hum + .38 Rad + 1.05 Fem + .64 Tib + 63.38 ± 3.74	.827
-.06 Hum + .53 Ulna + 1.28 Fem + .78 Fib + 67.55 ± 3.47	.832		.64 Hum + .21 Ulna + 1.07 Fem + .84 Fib + 60.76 ± 3.71	.830
1.57 (Hum + Rad) + 78.25 ± 4.21		.739	1.75 (Hum + Rad) + 67.90 ± 4.15	.782
1.56 (Hum + Ulna) + 75.96 ± 4.27		.731	1.73 (Hum + Ulna) + 66.01 ± 4.19	.777
1.33 Fem + .89 Tib + 73.48 ± 3.53	.825		1.32 Fem + 1.01 Tib + 69.24 ± 3.82	.819
1.31 Fem + 1.00 Fib + 70.38 ± 3.49	.829		1.31 Fem + 1.14 Fib + 65.89 ± 3.76	.825
1.12 (Fem + Tib) + 74.33 ± 3.55		.823	1.17 (Fem + Tib) + 70.05 ± 3.82	.819
1.16 (Fem + Fib) + 71.23 ± 3.49		.829	1.23 (Fem + Fib) + 65.17 ± 3.76	.825

that multiple regression equations are not necessarily the most desirable for stature prediction. The constants to be applied vary considerably from right bone to left bone, indicating the extreme sensitivity to slight differences in correlation. The greater stability of single regression correlation coefficients is evidenced by the fact that the constants are almost identical for right and left bones when length of the femur plus tibia or length of the femur plus fibula is used as a single variable; these constants are also very similar to the corresponding constants obtained in the previous study. It should be noted, however, that the average length of the right and left bone of any given pair might have resulted in somewhat greater precision of estimate.

The instability of the multiple regression coefficients from sample to sample for these types of data is due to the fact that the intercorrelation coefficients among the bone lengths are very high, and consequently the coefficients in any two columns of the matrix of intercorrelations are practically equal, or at least proportional. It can be shown mathematically that in this circumstance the multiple regression coefficients are determined primarily by the chance differences between the correlation coefficients, and that these chance differences mask the fact that the coefficients are essentially indeterminate. Thus, while the multiple regression equation technique does indicate the maximum correlation obtainable in a given sample, it capitalizes on all sampling variations with the result that the equations are not likely to be suitable for a new sample and when so applied may actually yield less precise estimates than would be obtained from the femur, tibia or fibula alone. Therefore, equations employing the sum of the lengths of femur and tibia or of femur and fibula are recommended for the prediction over those of the multiple regression technique because of their greater stability from sample to sample.

Regression equations of stature involving the sum of the lengths of femur and tibia and of femur and fibula were averaged in both instances for right and left bones of both the White and Negro series and are presented in figure 3 with

the corresponding regression equations based on the previous study. It is evident that the corresponding equations of the two studies are quite consistent and also that they differ between the two racial groups.

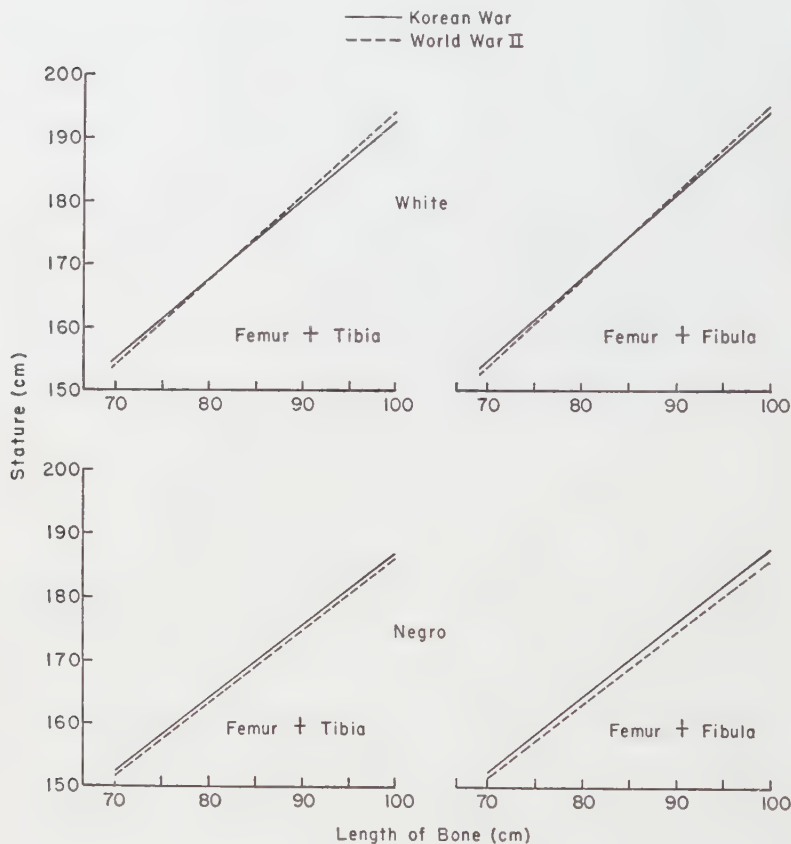


Fig. 3 Comparison of estimates of stature of White and Negro males of Korean War and World War II series according to the sum of lengths of femur and tibia and of femur and fibula.

Growth of American White males after 17 years of age

It was noted earlier that the average stature of White males of the Korean War series was significantly shorter for the

17 year old group than for the 18 year old group and that the data pertaining to those under 18 years of age were excluded from the computation of prediction equations. A further examination of the stature-age relationship for White males (table 2) reveals the fact that the average stature increased significantly from 17 to approximately 23 years of age. These data are particularly interesting since the same age group of World War II White males (*op. cit.*, table 1, p. 470) showed no significant increase. Other series of stature data based on 41,850 records of American White males and on 6,835 records of American Negro males, all measured in 1946, were compiled by the Quartermaster Research and Development Command, U. S. Army (Newman, '50). A comparison of the data of Newman's series and the present series are shown in figure 4. While the average statures of both White groups are in close agreement at ages 17 and 18 years, the average statures at succeeding age levels are all taller in the Korean War series than in Newman's series, and the curve has a much steeper rise; the difference between the curves of the two Negro series is not as distinct, but the present series is somewhat taller at all but two age levels.

The above findings suggest that on the average the generation of young American White males (represented in the Korean War) continued to grow in stature to an older age than did the former generation (measured in 1946), i.e., a larger percentage of individuals of the present study showed an increase in stature up to 23 years of age than did those of the earlier period. The increase which occurred during years after the long bones of the lower limb may be expected to have reached maximum length (epiphyses fused to diaphysis no later than 20 years of age), but before the bodies of some vertebrae have stopped growing (epiphyses not fused to bodies of all vertebrae until approximately 23 or more years of age), might be attributed to the vertebral column. This idea was mentioned by Randall ('49) in his study of 17,341 White military males ranging in age from 17 to 26 years. (The mean statures correspond very closely to those of the

larger series of this period, Newman, '50.) He considered, also, that it might be a result of more erect posture acquired during the period of military service, but concluded that "evidence is strong that the American White male attains his

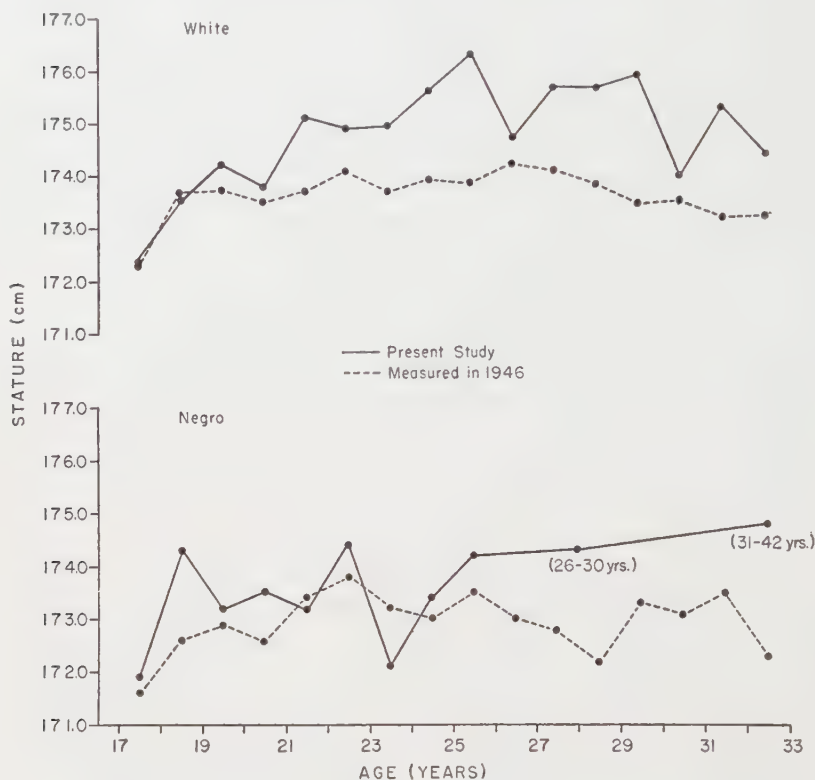


Fig. 4 Comparison of mean statures of White and Negro males of present study with those measured in 1946 (41,850 Whites and 6,835 Negroes) according to age.

adult stature, as an average, in the 18th year." Unless military training had brought about more erect posture in more individuals of the present study than of the 1946 series, which seems unlikely, the significant increase in mean stature after 18 must be attributed to growth of a larger number of individuals than heretofore. Whether this growth is a result of epiphyseal union occurring throughout the skeleton at an

older age in more individuals of the present than of the previous series, or that there is a marked increase of growth in the vertebral column after 18 years is the question. The present data support the latter hypothesis since there is increase in stature but not in length of long bones. The consequence is a change, however slight, in the relationship between bone length and maximum stature of the present series over that of the previous series.

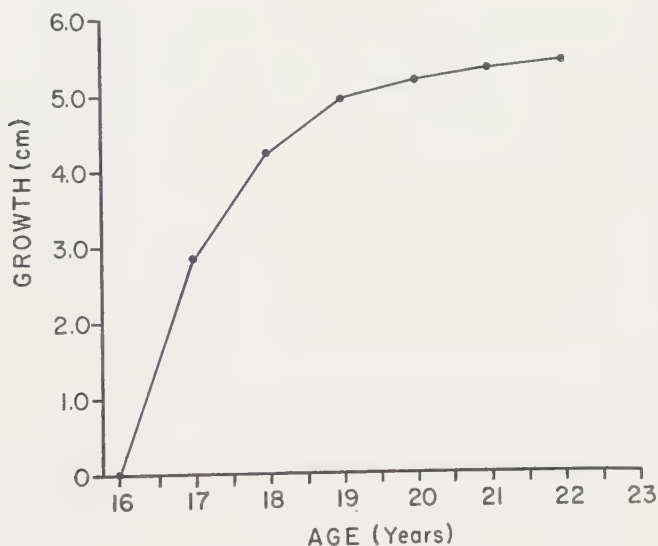


Fig. 5 Growth curve based on longitudinal study of 44 American White males (Child Research Council of the University of Colorado).

Since growth curves are most suitably studied by means of longitudinal data, it seemed desirable to obtain data from a contemporary longitudinal study in order to see whether or not the evidence of continued growth after 18 years suggested in the present cross-sectional study is substantiated. Stature records of 44 American White males in the desired age span were made available by the Child Research Council of the University of Colorado.⁶ Stature had been measured at

⁶ Through the courtesy of Dr. Marion M. Maresh and Dr. Edith Boyd, Child Research Council, University of Colorado School of Medicine.

yearly, or more frequent, intervals up to 1956. From these data a growth curve between 16 and 22 years was obtained (fig. 5); it may be noted that there was an average growth of 1.25 cm between ages 18 and 22. The average increments of growth after 16 are, for each successive year, almost exactly one-half that of the preceding year. Thus, the curve in figure 5 shows an excellent fit to the equation,

$$S_x - S_{16} = 5.68 \left[1 - \frac{1}{2}^{(x-16)} \right] \text{ cm,} \quad (1)$$

where S_x means stature at age x . The coefficient, 5.68, in this equation represents the increase to be expected on the average from 16 years of age to the year in which maximum stature is attained. It is precisely double the increment from age 16 to 17. In other words, an individual may be expected to grow as much more after 17 years as he did between 16 and 17 years; as much more after 18 years as he did between 17 and 18 years, and so on. These are average estimates, and as such are comprised of increments which fluctuate from individual to individual. However, for this same group, using individual growth increments from 16 to 17 years of age, it was found that the maximum stature could be estimated with a standard error of only 1.2 cm. The above equation can be used for individual prediction in the general form,

$$S_x - S_{16} = 2 (S_{17} - S_{16}) \left[1 - \frac{1}{2}^{(x-16)} \right] \text{ cm,} \quad (2)$$

or even in a more general form,

$$S_{x_1} - S_{x_2} = 2 (S_{x_1+1} - S_{x_1}) \left[1 - \frac{1}{2}^{(x_2-x_1)} \right] \text{ cm.} \quad (3)$$

Another set of records of a group of 81 undergraduate athletes at Washington University, whose stature had been measured to the nearest one-fourth inch at varying intervals while they were in college, were made available, also.⁷ Of 40 boys for whom stature had been recorded or could be obtained by interpolation at 18 and again at 19 years of age, 23 or 57.5% showed growth of at least 0.25 inch (.63 cm); the average growth for these 40 boys is 0.37 inch (0.94 cm). Of 46

⁷ Through the courtesy of Dr. Llewellyn Sale, Jr., Director of Student Health Service, Washington University.

boys for whom stature measurements were available at 19 and again at 20 years of age, 17 or 37% showed growth; the average increase at this age interval is 0.26 inch (0.66 cm). From ages 20 to 21, six of 35 boys (17%) showed growth; the average increase is 0.11 inch (0.28 cm).

The data from both these longitudinal studies provide confirmation of the finding in the data of the cross-sectional study that the majority of American White males today continue to increase in stature after 18 years of age. For each successive year thereafter, up to 21 years, the number continuing to grow in stature is reduced, and from 21 years of age and upward it may be considered that maximum stature has been attained. Since a large proportion of the White series of the present study were younger than 21 years at the time of induction when stature was measured, the prediction equations in table 3 based on subjects 18 years of age and over could be expected to yield stature estimates for individuals over 21 which are too short and estimates for individuals 18 to 21 which are too tall. This would be true whether the additional growth between 18 and 21 years occurred only in the vertebral column or whether it involved the long bones also, since in the latter instance the lapse of time occurring between induction (when stature is measured) and death (after which long bones are measured) would result in a discrepancy.

On the basis of this evidence from the White series, regression equations for estimation of stature have been recomputed for both White and Negro series using data only from those individuals who were 21 years or older at the time of induction when stature was measured (table 8). Whereas no changes of note are found in the Negro series, the equations for the White series yield an estimate of stature which is approximately 0.5 cm taller for a given length of long bone than that obtained from equations including the 18 to 21 year olds. The stature estimates are also, of course, taller than are those determined from equations based on World War II data. The increase in estimated stature is due not to any significant change in correlation, nor to the slope of the regression equa-

TABLE 8

Means and standard deviations (S.D.) of statures and bone lengths, correlation coefficients (r) bone lengths with stature, and equations for estimation of stature (with standard errors) according to side and racial group of those 21 years and older.

BONE AND SIDE	CASES	STATURE		BONE LENGTH		CORRELATION COEFFICIENT	ESTIMATION EQUATION
		Mean	S.D.	Mean	S.D.		
	no.	cm		cm		r	cm
White							
Hum R	1475	165.375	6.747	33.703	1.724	.738	$2.89 H_R + 77.97 \pm 4.4$
Hum L	1445	175.161	6.667	33.622	1.692	.731	$2.88 H_L + 78.33 \pm 4.4$
Rad R	1418	175.221	6.769	25.343	1.288	.721	$3.79 R_R + 79.17 \pm 4.4$
Rad L	1364	175.075	6.653	25.174	1.259	.718	$3.79 R_L + 79.67 \pm 4.4$
Ulna R	1423	175.096	6.746	27.202	1.310	.707	$3.64 U_R + 76.08 \pm 4.4$
Ulna L	1382	175.087	6.679	27.043	1.288	.714	$3.70 U_L + 75.03 \pm 4.4$
Fem R	1159	174.973	6.830	47.102	2.395	.808	$2.30 F_R + 66.64 \pm 4.4$
Fem L	1171	174.982	6.811	47.250	2.396	.823	$2.34 F_L + 64.42 \pm 3.9$
Tib R	1274	175.053	6.730	38.437	2.259	.808	$2.40 T_R + 82.80 \pm 3.9$
Tib L	1240	175.156	6.769	38.561	2.237	.804	$2.43 T_L + 81.45 \pm 4.4$
Fib R	1126	174.951	6.665	38.265	2.108	.816	$2.58 Fi_R + 76.23 \pm 3.9$
Fib L	1125	175.151	6.704	38.324	2.099	.816	$2.61 Fi_L + 75.12 \pm 3.9$
Negro							
Hum R	210	173.657	6.635	34.114	1.719	.723	$2.79 H_R + 78.48 \pm 4.4$
Hum L	213	173.526	6.729	34.037	1.739	.746	$2.89 H_L + 75.16 \pm 4.4$
Rad R	202	173.584	6.651	26.667	1.390	.679	$3.25 R_R + 86.92 \pm 4.8$
Rad L	200	173.625	6.737	26.536	1.356	.686	$3.41 R_L + 83.14 \pm 4.9$
Ulna R	207	173.614	6.673	28.538	1.418	.692	$3.26 U_R + 80.58 \pm 4.4$
Ulna L	194	173.562	6.797	28.360	1.355	.681	$3.42 U_L + 76.57 \pm 4.9$
Fem R	192	173.625	6.322	48.115	2.327	.784	$2.13 F_R + 71.14 \pm 3.9$
Fem L	184	173.946	6.727	48.375	2.361	.790	$2.25 F_L + 65.10 \pm 4.1$
Tib R	193	173.860	6.254	40.374	2.164	.754	$2.18 T_R + 85.84 \pm 4.1$
Tib L	186	173.763	6.622	40.346	2.297	.747	$2.15 T_L + 87.02 \pm 4.4$
Fib R	169	173.976	6.437	40.085	2.035	.767	$2.43 Fi_R + 76.57 \pm 4.1$
Fib L	173	173.607	6.619	39.955	2.046	.738	$2.39 Fi_L + 78.11 \pm 4.4$

tions, but rather to the taller average stature of this group limited to 21 years and over when compared with the group including those from 18 to 21 years of age, although the average bone lengths are almost identical in the two groups.

These equations (table 8) derived from data pertaining only to individuals 21 years and older (with the large majority under 30 and the oldest only 46, see table 2, p. 83) will provide the most precise estimates of stature for the young adult⁸ American White and Negro male of the present generation. The equations may be approximately correct also for estimation of stature coincident with long bone lengths for those from 17 to 21 years of age, although no data are available to substantiate this fact. However, the stature problem confronting the American Graves Registration Service in its program of identification of skeletal remains is that of estimating stature from lengths of long limb bones and expecting the estimation to approximate the recorded stature. A closer approximation will result for those whose stature was recorded before 21 years of age, if a correction is added to the recorded stature for the growth which occurred after the stature was measured. In order to provide the correction for such discrepancy the average increase in stature for each successive half-year between 17 and 21 years of age has been determined.

The amount of correction is based on data pertaining to White males of the Korean War who had been inducted into service between the ages of 17 and 21 years and for whom measurements of either right or left femur or right or left fibula were available. The data were grouped according to age at induction and according to the lapse of time between induction and death, using one-half year intervals throughout. The average stature for each sub-group was estimated from the available long bone length (femur or fibula) using equations derived from White males 21 years or older. The

⁸ When stature is estimated for an individual over 30 years of age the estimate should be reduced by the amount of 0.06 (age in years -30) cm, (Trotter and Gleser, '51a).

differences thus obtained between the estimated and recorded statures yield a growth curve for each group with different age spans. The segments from the curves for the same age interval from each different age span were then combined in order to derive an average growth curve for ages from 17 to 21 years. The increment of stature between any two ages on this curve is the amount of correction to be added to observed stature (when measured before 21 years of age) in order to

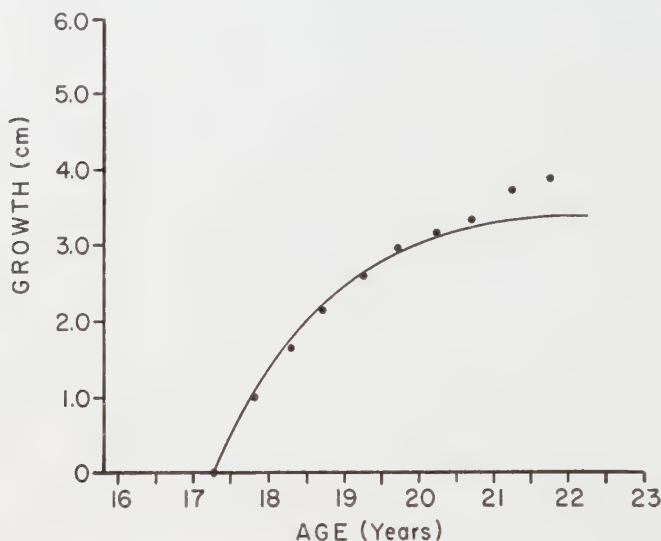


Fig. 6 Average increments of growth of White males of Korean War series (in one-half year intervals) from age 17 to 22 years and fitted theoretical curve, $s_x - s_{17.25} = 3.50 [1 - \frac{1}{2}^{(x-17.25)}]$ where x equals age.

determine the probable stature at the time of death. These empirical data are shown in figure 6, with a fitted theoretical curve of the type derived from the longitudinal data (equation 3) but using the constants derived from cross-sectional data. The equation on which the theoretical curve is based is

$$S_x - S_{17.25} = 3.50 [1 - \frac{1}{2}^{(x-17.25)}] \text{ cm.} \quad (4)$$

The two curves are an excellent fit up to age 20.5 years, but the theoretical curve slightly underestimates the last two points obtained empirically. These two points, however, are

based on relatively few cases and therefore are not very reliable. In consideration of the manner in which the empirical points were obtained, i.e., using stature estimates based on lengths of different long bones and combining increments for different age groups over like intervals of time, the closeness of their fit to the theoretical curve is remarkable and lends confidence in the use of cross-sectional data for determining longitudinal trends. Using equation 4 the amount of growth to be expected during any half-year interval (or multiple there-

TABLE 9

Average increase (cm) in stature of American White males in one-half year intervals and multiples thereof from 17 to 21 years of age

LENGTH OF INTERVAL	AGE IN ONE-HALF YEAR INTERVALS							
	17-17.5	17.5-18	18-18.5	18.5-19	19-19.5	19.5-20	20-20.5	20.5-21
<i>yrs.</i>								
$\frac{1}{2}$	1.03	.72	.51	.36	.26	.18	.13	.09
1	1.75	1.23	.87	.62	.44	.31	.22	.16
$1\frac{1}{2}$	2.26	1.59	1.13	.80	.57	.40	.29	.20
2	2.62	1.85	1.31	.93	.66	.47	.33	
$2\frac{1}{2}$	2.88	2.03	1.44	1.02	.73	.51		
3	3.06	2.16	1.53	1.09	.77			
$3\frac{1}{2}$	3.19	2.25	1.60	1.13				
4	3.28	2.32	1.64					
$4\frac{1}{2}$	3.35	2.36						
5	3.39							

of) between 17 and 21 years of age was determined. The results are listed in table 9. The increase appropriate to the interval of time which elapsed between measurement of stature and death, for individuals whose stature was measured between 17 and 21 years of age, may be found and should be added to observed stature. The resultant figure will approximate the stature at the time of death and thus the stature which is estimated from the long bone lengths.

The evidence that average maximum stature of American White males is increasing and that the increase is occurring after 18 years of age resulting in a change in the relationship of maximum stature to long limb bone lengths poses a serious

problem for those interested in the practical application of prediction equations. It is very likely that this change is responsible for the larger standard error of estimate in the present study than in the first study, since estimates can be expected to be less accurate during a period of flux than when relationships are stable. Undoubtedly some individuals 21 years of age and older, of the present study, had grown after 18 years of age while others had not, thus providing a greater spread of statures among individuals with any given bone length. Not only is prediction of stature less precise as a result of this changing relationship, but the equations for prediction should be checked against new series from time to time and modified as changes in relationship occur. This is true of equations for prediction of Negro stature as well as for White, since certain trends toward change in the proportion of body segments of American Negroes noted in this study may continue. Furthermore, it is not unlikely that during the next few years the American Negro also may show an increase in stature comparable to that found in the present White male series, particularly if this trend is due to improvement in nutrition or other conditions which have been designated collectively by the term "secular factor."

Comparison of stature estimates from lengths of long bones of the five racial series

The regression equations for estimation of stature from right and left bone lengths were combined ⁵ for each of the five racial groups; the White group is limited to individuals 21 years of age and older (data recorded in table 8) and the Negro, Mongoloid, Mexican and Puerto Rican groups to individuals 18 years and older (recorded in table 3). The resultant equations with sample estimates of each for given bone lengths are presented in table 10 and the regression lines of these equations are shown in figure 7.

An examination of either the table or the figure immediately reveals that the White male tends to be taller for a given

⁵ See footnote 5, page 92.

TABLE 10

Equations for estimation of maximum stature (cm) (averaged for right and left bone lengths) for all five racial series of the Korean War, with sample estimates (cm) of each for given bone lengths (cm)

LENGTH	WHITE	NEGRO	MONGOLOID	MEXICAN	PUERTO RICAN
Humerus	2.89 Hum + 78.10 Estimate	2.88 Hum + 75.48 Estimate	2.68 Hum + 83.19 Estimate	2.92 Hum + 73.94 Estimate	2.62 Hum + 82.82 Estimate
30.0	164.80	161.88	163.59	161.54	161.42
35.0	179.25	176.28	176.99	176.14	174.52
40.0	193.70	190.68	190.39	190.74	187.62
Radius	3.79 Rad + 79.42	3.32 Rad + 85.43	3.54 Rad + 82.00	3.55 Rad + 80.71	3.28 Rad + 86.10
20.0	155.22	151.83	152.80	151.71	151.70
25.0	174.17	168.43	170.50	169.46	168.10
30.0	193.12	185.03	188.20	187.21	184.50
Ulna	3.67 Ulna + 75.55	3.20 Ulna + 82.77	3.48 Ulna + 77.45	3.56 Ulna + 74.56	3.30 Ulna + 79.94
22.0	156.29	153.17	154.01	152.88	152.54
25.0	167.30	162.77	164.45	163.56	162.44
30.0	185.65	178.77	181.85	181.36	178.94
Femur	2.32 Fem + 65.53	2.10 Fem + 72.22	2.15 Fem + 72.57	2.44 Fem + 58.67	2.10 Fem + 72.61
40.0	158.33	156.22	158.57	156.27	156.61
45.0	169.93	166.72	169.32	168.47	167.11
50.0	181.53	177.22	180.07	180.67	177.61
Tibia	2.42 Tib + 81.93	2.19 Tib + 85.36	2.39 Tib + 81.45	2.36 Tib + 80.62	2.00 Tib + 92.53
30.0	154.53	151.06	153.15	151.42	152.53
35.0	166.63	162.01	165.10	163.22	162.53
40.0	178.73	172.96	177.05	175.02	172.53
Fibula	2.60 Fib + 75.50	2.34 Fib + 80.07	2.40 Fib + 80.56	2.50 Fib + 75.44	2.12 Fib + 88.76
30.0	153.50	150.27	152.56	150.44	152.36
40.0	179.50	176.56	176.56	175.44	173.56
45.0	192.50	185.37	188.56	187.94	184.16

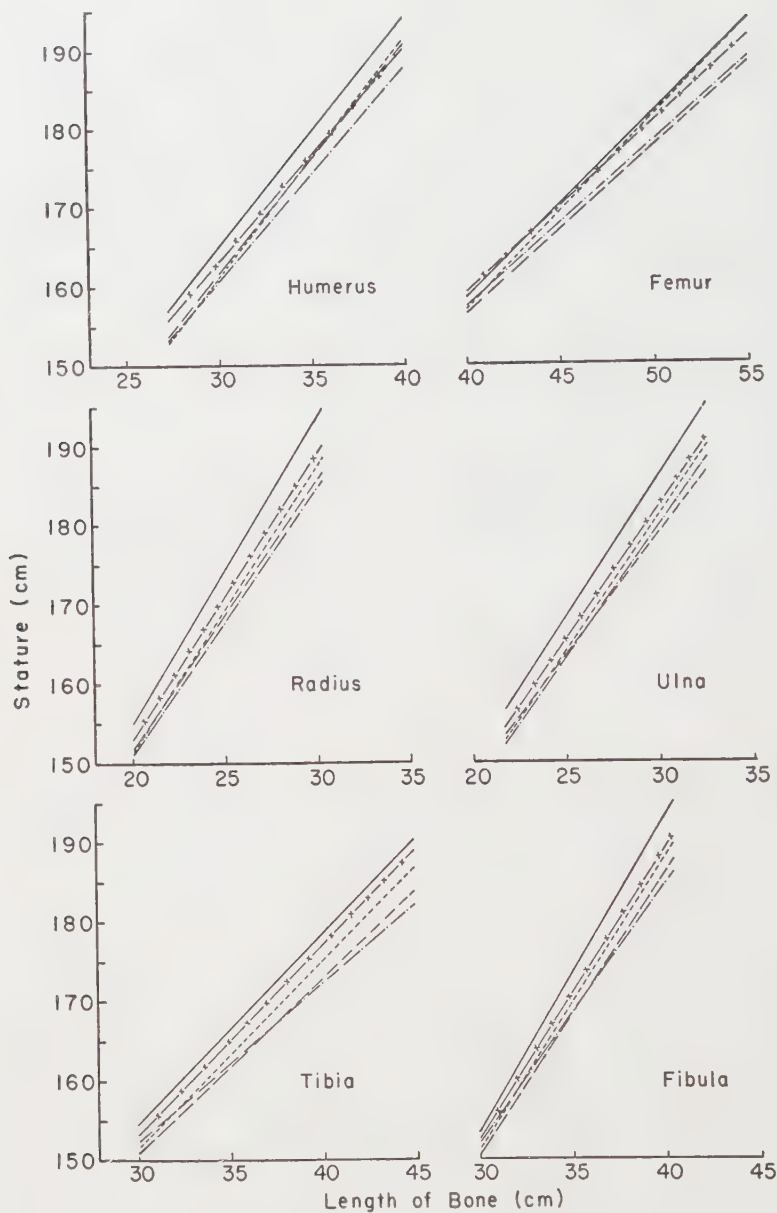


Fig. 7 Comparison of estimates of stature of American White, Negro, Mongoloid, Mexican and Puerto Rican series according to length of long bones.

length of long limb bone than does any of the other series. This is particularly evident for the equations of stature based on radius and ulna, and holds also for the equations based on the other long bones with perhaps the least difference among equations based on femur. Statures of the Mongoloid and Mexican series are approximately as tall relative to their femur lengths as are statures of the White series, but those of the Negro and Puerto Rican series are considerably shorter.

The equations for the Negro and Puerto Rican series are practically identical for every bone except the humerus, and the equations of both these series differ distinctly from the equations of the other three series. Thus, the similarity between the proportion of length of limb to stature of the Negro

TABLE 11

Observed statures (cm) of individual American Indians and Mexicans from World War II and their stature estimates (cm) determined from equations based on the Mongoloid and Mexican series of the Korean War.

OBSERVED STATURE	STATURE ESTIMATES					
	Mongoloid equations			Mexican equations		
	Hum	Fem	Fib	Hum	Fem	Fib
American Indians						
166.4	174.0	164.6	170.8	172.9	163.3	169.4
167.6	168.2	169.3	167.2	166.5	168.5	165.7
170.2	168.0	171.4	170.4	166.4	170.8	168.9
170.2	167.8	169.6	169.8	166.1	168.7	168.4
170.2	172.3	174.0	169.8	171.0	173.8	168.4
172.7	169.5	172.2	166.7	168.0	171.8	165.2
172.7	170.2	170.8	169.1	168.8	170.2	167.7
174.0	175.8	178.9	176.6	174.8	179.3	175.7
Av. 170.5	170.7	171.0	170.0	169.3	170.8	168.7
Deviation	+ .2	+ .5	— .5	—1.2	+ .3	—1.8
Mexicans						
160.0	166.9	165.4	165.4	165.0	164.1	164.3
165.1	173.4	171.1	168.5	172.0	170.6	170.0
167.6	170.4	170.9	168.8	168.8	170.3	167.3
167.6	167.7	168.1	169.1	165.8	167.2	167.7
170.2	170.3	172.7	168.6	168.6	172.2	167.2
170.2	169.0	173.2	172.2	167.0	172.6	171.1
Av. 166.8	169.6	170.2	168.8	167.9	169.5	167.9
Deviation	+2.8	+3.4	+2.0	+1.1	+2.7	+1.1

and Puerto Rican becomes evident, even though the average stature of the Puerto Rican is approximately 7 cm shorter than of the Negro. These two series have the shortest stature relative to their long bone lengths of any of the five racial groups studied herein. From the present evidence it appears that the same equations will provide estimates of stature for either of the two groups.

The equations derived from the Mongoloid and Mexican series are also similar, but the similarity is not as pronounced as it is between those derived from the Negro and Puerto Rican series. The Mongoloid, Mexican and Puerto Rican series are relatively small in number and thus the equations derived from them are subject to considerable sampling error; in addition, the Mongoloid series is heterogeneous, consisting of Japanese, Hawaiians, Filipinos, American Indians, etc., (see table 1). As a test, the equations for humerus, femur and fibula, derived from the Mongoloid and Mexican series, were applied to data (available from World War II) of small groups of American Indians and Mexicans (8 and 6, respectively). The results are shown in table 11. From the Mongoloid equations the average stature estimates (based on humerus, femur and fibula) of the American Indians are quite accurate and, excepting that based on femur, are more precise than estimates based on the comparable Mexican equations. On the other hand, both the Mongoloid and the Mexican equations result in stature estimates which are too tall for Mexicans of World War II, but, as expected, the Mexican equations provide more precise estimates than do the Mongoloid equations. Thus, until further evidence is available, the equations derived from the Mexican series are recommended for estimating stature of Mexicans and the equations from the Mongoloid series for estimating stature of American Indians.

Precision of stature estimates from long bones

Since the first study (based on measurements of stature during life and of long bones after death) was reported ('52),

discussions of precision of stature estimates and recommendations for procedure in order to obtain the greatest precision in estimates have been presented.

The first of these was by Boyd and Trevor in 1953, presumably written before they had access to the 1952 study. In discussing the discrepancy between estimates based on the formulae of Pearson (1899) and of Dupertuis and Hadden ('51), they suggested that it more likely resulted from differences in technique of measuring stature than from differences between the populations concerned. They then recommended the provisional adoption of the general formulae of Dupertuis and Hadden which had been derived from weighted averages of Pearson's data (French Whites) and their own (American Whites and Negroes), adding that these formulae "represent a compromise but, as far as it has been able to test them, are superior to any others designed for a similar purpose." They reproduced 10 of the general formulae and further recommended that "The most satisfactory estimate of stature is found by using as many formulae as possible and then adding and dividing the results to obtain a mean value." Presumably, this recommendation implies averaging estimates based on all available formulae derived from the same series of data. It should be noted that formulae derived from any given study include regression equations involving both a single bone length and the sum of the lengths of two bones and, also, multiple regression equations involving lengths of two or more bones.

Later in the same year, Keen ('53) discussed the reliability of estimates of stature from long bones and criticized the use of general formulae. He re-emphasized that the standard error of estimate is a measure of expected accuracy of a stature estimate of an individual who belongs to the same population from which the equation was derived. If the individual is from a different population a different error of unknown size would be expected.

Still later in the same year, Harrison ('53), desirous of increasing the accuracy of stature estimates and thus proving

the usefulness of such estimates for legal purposes, not only combined estimates derived from the ten general formulae of Dupertuis and Hadden (and from the ten formulae of Trotter and Gleser) but also maintained that the 5% fiducial limits based on the standard error of the mean of these estimates provide limits "outside which we should expect the true height to lie in less than 5 in 100 cases examined." Nevertheless, of the 5 cases presented the statures of 2 (or 40%) estimated by this method using the Dupertuis and Hadden formulae fell without these limits.

In 1955, Keen protested again these fallacies with a well substantiated plea for the rejection of the method of pooling and averaging estimates.

As a supplement to Keen's efforts it seems advisable to discuss further the crucial question of the meaning of precision of stature estimates and to indicate pitfalls in the interpretation and use of regression equations for estimation of stature from long bones.

From the findings of both the earlier ('52) and present studies based on military subjects, there can be no question of the need for different equations for estimating stature from long bones of American White, Negro and Mongoloid populations in order to obtain the greatest precision in estimates of stature. The evidence suggests further that different equations may be needed for the same racial group in successive generations. Thus, present-day formulae may introduce a systematic bias in estimates of stature of individuals of past generations. These facts, admittedly, would make it difficult to decide what formula to use in certain situations. However, the investigator is only deceiving himself when he attempts to solve this dilemma by averaging equations obtained at different times and/or from different races, and believes that the error of estimate will be thereby reduced. Such a procedure actually increases the error of estimate over that of the most appropriate equation since additional error is introduced through the equations which are not pertinent.

As an example, the problem of estimating stature from a tibia of 40.0 cm in length will serve. If the bone had come from an American White male of the present generation the stature would be estimated at 178.73 cm and it could be stated with 95% certainty that the actual stature had been between 170.73 and 186.73 cm. The broad range (16 cm) is due to the fact that American White males with tibiae of this length (40.0 cm) vary in stature to this extent even though they are of the same population. Similarly, if the tibia had been that of an American Negro, the stature would be estimated at 172.96 cm with 95% certainty that the true stature had been between 165.14 and 180.78 cm. However, if the race were unknown and these estimates were averaged (175.84 cm) it could be said only that the true stature had been between 166.3 and 185.4 cm, a range of 19.1 cm. This procedure of averaging the estimates would be justified only on the basis of the somewhat dubious assumption that the population from which the bone had come was composed equally of Whites and Negroes.

A somewhat different problem is posed in the averaging of estimates obtained from formulae involving different long bones when all the formulae have been derived from a single population. In this circumstance it would be possible to increase the precision of the estimate by using formulae involving different bones provided each bone adds new information about stature. Since bone lengths are linearly related to stature, the method of determining whether or not more than one bone adds new information is that of partial correlational and multiple correlational techniques. The extent to which combining estimates from different bones, using the most *effective weighting* rather than simply averaging them, will provide more precise estimates of stature is indicated in a comparison of tables 3 and 7. For example, in the White series combining the femur and fibula of the right side to obtain a stature estimate reduces the standard error of estimate to 3.62 cm, from that of 3.86 cm when the right fibula is used alone. With the weighted combination of right humerus, ulna, femur and fibula, the standard error is 3.61 cm — a negligible

improvement, because the upper limb bones give *no new information* about stature over that which had already been obtained from lower limb bones.

But, if the estimates obtained from two bones with rather different standard errors of estimate, such as humerus and femur, are simply averaged the estimate may actually be less precise than that from using only the equation with the smaller standard error. That is to say, for a series of individuals, the average of the estimates will deviate from the actual stature in the majority of cases by a larger amount than would a single estimate from the equation with the smallest standard error of estimate. The following example based on data (cm) from 6 cases chosen at random from the present series of Mexican remains will serve to illustrate the point:

CASE NO.	LENGTH		OBSERVED STATURE	ESTIMATE FROM		AVERAGE OF ESTIMATES	DEVIATION FROM OBSERVED STATURE OF	
	Hum.	Fem.		Hum.	Fem.		Av. est.	Fem. est.
1	32.3	45.7	167.0	168.3	170.2	169.25	2.25	3.2
2	31.6	43.0	163.0	166.2	163.6	164.90	1.90	0.6
3	32.2	46.1	171.0	168.0	171.2	169.60	1.60	0.2
4	35.2	48.0	178.0	176.7	175.8	176.25	—1.75	—2.2
5	33.0	47.6	175.0	170.3	172.9	171.60	—3.40	—2.1
6	31.0	45.0	167.0	164.5	166.5	165.50	—1.50	—0.5
Average absolute dev.							2.07	1.47

In four of the six cases the deviation from observed stature is larger for the averaged estimates than for the estimates based on the femur alone, and the average absolute deviation (disregarding sign) is 2.07 cm for the averaged estimate and only 1.47 cm for that based on femur alone. From this example can be seen the fallacy of Harrison's claim that the effect of averaging estimates based on several bones will be "to reduce the standard error in proportion to the square root of the number of bones used" (p. 212, *op. cit.*). Since high correlations exist among long limb bone lengths, the procedure of averaging estimates based on different bones and/or on combinations of these bones is merely repeating the information

provided by one bone and cannot add to the precision of the estimate.

Still another error in the interpretation and use of regression equations may be made in testing the precision of stature estimates by plotting them as ordinate against the observed statures as abscissa. To do so will suggest that the stature estimates are too tall for short individuals and too short for tall individuals — a typical phenomenon of regression equations. Stature estimates are merely a linear function of bone lengths and such a graph will demonstrate the distribution of bone lengths according to stature. Thus, a line connecting the averages of estimated statures (each average comprising the estimates for all individuals with the same observed stature) will correspond to the regression equation of *bone length* on stature which is always different from the regression equation of stature relative to bone length unless the correlation were unity. The proper way to test visually the precision of stature estimate is to plot the observed statures as the ordinate with the estimated statures as abscissa. If the equation is applicable the points should be distributed fairly evenly above and below the line where true stature equals estimated stature.

In the interest of obtaining the greatest precision in stature estimates the warnings discussed above are listed:

1. Do not combine formulae obtained by different investigators, based on different races or populations in different geographical areas, nor pertinent to different generations.
2. Do not estimate stature by determining the average of estimates obtained from several equations, each of which is based on a different bone or on a combination of bones.
3. Do not plot estimated stature against observed stature in order to test the precision of regression equations.

Order of preference of equations

In all studies of bone length-stature relationship the lower limb bones have been shown to have lengths which are cor-

related more highly with stature than have the upper limb bones. Therefore, it can be stated as a general rule that in no case should lengths of upper limb bones be used in the estimation of stature unless no lower limb bone is available.

In order to facilitate the choosing of the equation for stature estimation with the least standard error of estimate, the various equations derived from the American male White, Negro, Mongoloid and Mexican series are presented in table 12 in order of preference. In view of the evidence given above

TABLE 12

Regression equations for estimation of maximum, living stature (cm) of American male Whites, Negroes, Mongoloids and Mexicans in order of preference according to standard errors of estimate.¹

WHITE		NEGRO	
1.31 (Fem + Fib) +	63.05 ± 3.62	1.20 (Fem + Fib) +	67.77 ± 3.63
1.26 (Fem + Tib) +	67.09 ± 3.74	1.15 (Fem + Tib) +	71.75 ± 3.68
2.60 Fib +	75.50 ± 3.86	2.10 Fem +	72.22 ± 3.91
2.32 Fem +	65.53 ± 3.94	2.19 Tib +	85.36 ± 3.96
2.42 Tib +	81.93 ± 4.00	2.34 Fib +	80.07 ± 4.02
1.82 (Hum + Rad) +	67.97 ± 4.31	1.66 (Hum + Rad) +	73.08 ± 4.18
1.78 (Hum + Ulna) +	66.98 ± 4.37	1.65 (Hum + Ulna) +	70.67 ± 4.23
2.89 Hum +	78.10 ± 4.57	2.88 Hum +	75.48 ± 4.23
3.79 Rad +	79.42 ± 4.66	3.32 Rad +	85.43 ± 4.57
3.76 Ulna +	75.55 ± 4.72	3.20 Ulna +	82.77 ± 4.74
MONGOLOID		MEXICAN	
1.22 (Fem + Fib) +	70.24 ± 3.18		
1.22 (Fem + Tib) +	70.37 ± 3.24		
2.40 Fib +	80.56 ± 3.24	2.44 Fem +	58.67 ± 2.99
2.39 Tib +	81.45 ± 3.27	2.50 Fib +	75.44 ± 3.52
2.15 Fem +	72.57 ± 3.80	2.36 Tib +	80.62 ± 3.73
1.68 (Hum + Ulna) +	71.18 ± 4.14		
1.67 (Hum + Rad) +	74.83 ± 4.16		
2.68 Hum +	83.19 ± 4.25	3.55 Rad +	80.71 ± 4.04
3.54 Rad +	82.00 ± 4.60	3.56 Ulna +	74.56 ± 4.05
3.48 Ulna +	77.45 ± 4.66	2.92 Hum +	73.94 ± 4.24

¹ When a stature estimate of a White male is to be compared with a stature measurement taken before the individual was 21 years of age the measured stature should be increased according to the time lapse between measurement and death (see table 9).

When stature is estimated for an individual over 30 years of age the estimate should be reduced by the amount of 0.06 (age in years — 30) cm, (Trotter and Gleaser, '51a).

(p. 112) the equations based on the Negro series are believed to be appropriate for Puerto Ricans. The Mexican series is so small that the data are inadequate for the derivation of formulae based on the sum of bone lengths so none are given. It is recommended for any individual remains that only one equation be used and that this one should be the equation with the least standard error of estimate according to the bones which are available.

SUMMARY

This study of estimation of stature from length of long limb bones is the second to be based on measurements of stature during life and of bones after skeletonization. The first study was based on American military males who were casualties of World War II, the present study on casualties of the Korean War. The present data include much larger series of both Whites and Negroes than did the first study and, also, small series of Mongoloids, Mexicans and Puerto Ricans.

Regression equations for estimation of stature of American males of each of the five groups have been determined from these data. The relationships of stature to length of long limb bones differ sufficiently among the three major races (White, Negro, Mongoloid) to require different regression equations from which to derive the most precise estimates of stature for individuals belonging to each of these groups. The Puerto Rican group, although of shorter stature than the American Negro, presents in this series of data approximately the same relationship of stature to length of long bones as does the Negro group, and thus the equations for estimation of stature derived from the data of the Negro series are applicable to Puerto Ricans. The proportions found in the small sample of Mexicans differ sufficiently from those of any of the other four groups to indicate that more precise estimates of stature for Mexicans will be determined from equations derived from the data of the Mexican series than from any of the other four series.

The standard errors of estimates of stature from lengths of long bones are larger in the present series of White males

than in the series of the previous study. The primary reason for this difference is attributed to the evidence that stature and its relationship to long bone lengths are in a state of flux, since some individuals over 21 years of age with given bone lengths are taller today than were individuals six to ten years ago with the same bone lengths.

American White males of the present generation are continuing to grow up to at least 21, and possibly 23, years of age before maximum stature is attained. This finding is in contrast to that obtained from extensive World War II data in which there was no significant increase in stature after 18 years of age. The longer period of growth in stature of the present military series than of the World War II series and the nature of the growth curve for this terminal period were substantiated in two sets of longitudinal growth data, wholly unrelated to the military series. It is probable that growth in stature is occurring after 18 years of age in all groups in the U.S.A. at the present time. By using the theoretical growth curve with constants computed from the American White military data, averages of the amount of increase in stature for each one-half year interval are provided from age 17 to 21 years. These averages should be applied, when appropriate, to observed or "presumed stature." The application is indicated in identification problems which involve a time lapse between the measuring of stature and the completion of growth in stature.

On the basis of the difference found in stature-long bone length relationships between the World War II and Korean War series, it is indicated that equations for estimation of stature should be derived anew at opportune intervals.

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THE THICKNESS OF SUBCUTANEOUS FAT IN ELDERLY MEN ¹

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INTRODUCTION

The literature concerning measurements of subcutaneous fat contains a dearth of data on old people. Brožek and Keys' ('51) and Brožek's ('52) studies of the thickness of skinfold in adult males end at 57 years of age. Garn's ('53) radiographic study of leg fat contains few data on individuals past 50. In the present study an attempt was made to measure skinfold thicknesses in old as well as middle-aged males. Representative sites in many regions of the body (upper and lower limbs, trunk and face) were measured so that older and younger age groups could be compared in respect to the pattern of fat distribution as well as in respect to thicknesses of various skinfolds.

Sample

In order to study an adequate number of old persons, and to minimize the influence of wide differences in diet and mode of life, Wayne County General Hospital, Michigan, was selected for the study, and the work is confined to ambulatory male "patients." American Negroes and whites differ in

¹ The large number of elderly "patients" at Wayne County General Hospital and the reputation of the director, Dr. Samuel Jacobson, for interest in studies of the most diverse kinds, prompted us to approach him with a request to use that institution's facilities for the present survey. The willing cooperation of the director of the infirmary, Dr. H. J. Wells, of the nurses and staff, and the voluntary participation of the subjects made it possible to collect the data with maximum ease.

average skinfold thickness (Newman, '56); the Negroes and a few Mongoloids measured have therefore been excluded from the analysis. The ambulatory "patients" at the Wayne County General Hospital are there for a variety of reasons. Indigent persons or others lacking a place to live or preferring the life of a county institution are admitted when they present themselves at the gates. They need not have an established disabling ailment in order to be allowed to remain, but many have minor disabilities such as a slight deformity or arthritis. All the ambulatory "patients" do a little light work in the hospital. The 369 white individuals measured were selected at random from the males within the age range of 41 to 100 years.

METHODS

In this study subcutaneous fat has been measured by use of spring-loaded skinfold calipers. In using such measurements as an index of subcutaneous fat, it must be kept in mind that two thicknesses of skin are included in each pinch, and the measurement is affected by the density of underlying fascia, pressure of the calipers, consistency of the subcutaneous tissues and – dexterity of the anthropometrist. In the present study a Harpenden caliper (Edwards et al., '55) was used. It has a constant pressure of 10 gm per mm² and a face area of 6×9 mm; readings can be taken to the nearest 0.1 mm. All the measurements were taken by the same observer (Lee). As we are interested only in comparison within the series, we believe it is safe to assume that any systematic variability is in the subcutaneous fat and that any significant differences noted can reasonably be ascribed to differences in fat thickness.

Ten sites of the body were chosen for skin-pinch measurements. The left side of the body was measured in every case, except that when there was an abnormality on that side, the right side was measured. The subjects were measured while seated in such a position that the skin of the part to be measured was under the least possible tension. The sites selected were:

1. Face—an inch anterior and superior to the angle of the mandible over the masseter muscle. The cutaneous musculature barely reaches this site.
2. Chin—under the chin, in the midline.
3. Subscapular—just below the inferior angle of the scapula with arm hanging down.
4. Costal margin—in the midclavicular line.
5. Abdomen—at the level of the umbilicus, two inches from it.
6. Waist—in the midaxillary line, midway between the 10th rib and the iliac crest.
7. Upper arm—over the triceps, midway between tip of acromion and tip of elbow with the forearm flexed at 90°.
8. Forearm—on the lateral aspect at the midpoint of radius.
9. Thigh—on the anterior aspect, half way between the midinguinal point and the upper border of the patella (with the knee flexed at 90°).
10. Leg—on the posterior aspect, 2 inches below the crease opposite the knee.

Height and weight were taken on a physician's balance and were recorded to the nearest $\frac{1}{4}$ inch and $\frac{1}{4}$ pound respectively. The subjects were weighed with their hospital clothes. The clothing of 2 cases was actually weighed and the weight of clothing estimated on the basis of this experience, three or four pounds, was subtracted from the weight of each individual. The recorded weight is considered close to the nude weight. The subjects were asked to straighten up as much as possible during the measurement of height, and $\frac{3}{4}$ inch was subtracted from each reading as an allowance for the height of the shoes. Since the measurement of stature in old persons may be complicated by such factors as poor posture and change in intervertebral discs, a long bone (Tibia) was measured as a second index of length.

We inquired concerning the date of birth of each individual, and recorded the age to the last birthday. Average ages have been corrected by adding 0.5 yr. Sex, racial origin, disease if

any, and any change from customary weight were also recorded from the patient's statements.

FINDINGS

For purposes of analysis, the data are divided into 5-year age groups, those for individuals between 41 and 55 were combined into one group, as were also those for individuals between 80 and 100.

Median, mean, standard deviation of the mean and standard error were calculated for each measurement for each age group. The means and standard deviations are given in table 1; it may be seen that the standard deviations of skinfold measurements are large when compared with the means, whereas differences between means of the same dimension for different age groups appear relatively small and irregular.

To compare the means for different age groups it was decided that, in view of doubt concerning the exact age of some subjects and the slow age trends, if any, it would be best to compare with each other measurements of groups that average 15 or 20 years difference in age. Accordingly, we tabulated the differences between age groups I and IV, II and V, III and VI, IV and VII, I and V, II and VI, III and VII. As each set of measurements appears in two of these calculations, no set is given any greater weight than any other. The differences between the means, standard errors of these differences, the ratio of the former to the latter (t-score), and the probability (p) of the t-score being a matter of chance were then calculated, and t-scores are given in table 2.

There are more increases in fat thicknesses than decreases. Furthermore, 5 measurements (four of them increases) prove to be "statistically significant" at the 5% level of probability. A detailed analysis of all 70 comparisons, however, shows that there is no evidence of statistically significant age changes in subcutaneous fat measurements: we found only 8 (rather than the mean expected number 7) t-scores with a probability of 0.1 or less and 39 (rather than the mean expected number

TABLE 1

Average height, weight, length of tibia and skinfold thickness in different age groups

	I	II	III	IV	V	VI	VII
AGE GROUP (IN YEARS)	41-55	55-59	60-64	65-69	70-74	75-79	80 up
MEAN AGE (IN YEARS)	50.8	57.8	62.8	67.5	72.4	77.0	84.4
NUMBER	40-41	51-54	71-73	62-65	65-66	40-41	28-29
Height (in mm)							
Mean	1701.0	1689.8	1692.5	1653.3	1647.1	1644.3	1634.9
S. D.	65.0	63.0	66.3	68.5	71.2	58.6	72.7
Tibial length (in mm)							
Mean	378.1	375.0	376.3	366.4	371.7	370.6	372.0
S. D.	23.9	21.2	21.8	24.8	24.6	19.5	22.6
Weight (in kg)							
Mean	66.1	65.1	68.0	68.0	65.6	64.3	65.2
S. D.	10.0	10.1	12.3	10.2	12.2	10.5	12.6
Skinfolds (in mm)							
Face							
Mean	7.0	7.7	7.6	7.7	7.5	7.7	6.9
S. D.	1.9	2.7	2.2	2.6	2.3	2.3	2.7
Chin							
Mean	8.0	8.5	8.5	9.3	8.7	8.4	8.4
S. D.	2.5	3.2	2.8	3.2	3.1	2.4	3.0
Subscapular							
Mean	11.5	11.4	11.8	12.8	11.9	12.1	12.6
S. D.	5.1	5.5	4.8	4.5	5.3	4.8	3.8
Costal margin							
Mean	13.2	12.6	13.4	14.7	14.1	13.5	13.6
S. D.	7.3	6.7	6.6	5.8	7.6	6.4	6.6
Abdomen							
Mean	18.2	17.3	18.6	20.4	18.7	19.9	21.6
S. D.	9.0	9.8	8.4	7.6	8.8	9.3	8.8
Waist							
Mean	10.1	9.2	10.5	12.1	10.8	10.4	10.1
S. D.	5.1	4.3	5.2	6.0	5.8	4.5	4.6
Arm							
Mean	8.8	9.1	9.9	10.6	10.1	9.3	9.2
S. D.	3.3	4.2	4.3	4.3	4.2	3.4	3.5
Forearm							
Mean	5.6	5.2	5.5	6.5	5.5	5.1	4.6
S. D.	2.5	1.8	2.2	2.6	2.5	2.3	2.0
Thigh							
Mean	12.4	12.3	13.3	14.4	13.3	12.8	13.6
S. D.	6.8	6.7	6.5	7.3	7.3	8.4	7.6
Leg							
Mean	6.6	6.4	7.0	7.8	7.5	7.2	7.1
S. D.	2.8	2.5	2.7	3.3	3.5	3.0	2.7

of 35) in which $p < 0.5$. The present study thus shows no appreciable differences with age in the thickness of subcutaneous fat.

TABLE 2

t-test of height, weight, length of tibia and skinfold thickness between different age groups (actual age range in each group is shown in table 1)

AGE GROUPS	I and IV	II and V	III and VI	IV and VII	I and V	II and VI	III and VII
Height	3.61 ¹	3.45 ¹	3.98 ¹	1.12	4.02 ¹	3.49 ¹	3.49 ¹
Tibial length	2.41 ²	0.91	1.54	—0.61	1.77	1.21	0.50
Weight	—0.94	—0.23	1.67	1.06	0.24	0.36	1.00
Skinfolds							
Face	—1.52	0.40	—0.13	1.34	—1.10	0.00	1.30
Chin	—2.29 ²	—0.36	0.22	1.28	—1.33	0.19	0.19
Subscapular	—1.45	—0.49	—0.30	0.27	—0.49	—0.66	—0.80
Costal margin	—1.05	—1.13	—0.13	0.73	—0.59	—0.61	—0.18
Abdomen	—1.31	—0.77	—0.74	—0.62	—0.29	—1.27	—1.55
Waist	—1.82	—1.64	0.03	1.75	—0.62	—1.29	0.34
Arm	—2.28 ²	—1.26	0.76	1.58	—1.65	—0.27	0.76
Forearm	—1.64	—0.92	0.72	3.67 ¹	0.18	0.07	1.82
Thigh	—1.44	—0.74	0.32	0.45	—0.67	—0.27	—0.22
Leg	—2.09 ²	—2.07 ²	—0.44	1.12	—1.53	—1.48	—0.20

¹ Statistically significant at the 1% level.

² Statistically significant at the 5% level.

DISCUSSION AND CONCLUSION

In order to examine the relation between the rather constant size of the skinfolds and differences in general body form, we have included data for height, weight and tibial length in table 1. The mean height of each of the 4 age groups above 65 years of age is significantly shorter than that of each age group under 65. The decrease probably is in the main result of changes in the vertebrae, intervertebral discs and changes in posture. Nevertheless, it should be noted that the tibia length of group IV, the 65–69 year old group, is significantly shorter than that of any younger group and that older age groups also have average tibia lengths slightly (but not significantly) shorter than those of the younger age groups.

Three of the five statistically significant differences in skinfolds involve greater thickness in group IV than in group I.

Group IV, however, is notably shorter in tibia as well as in stature than group I so, in view of the evidence that tibia length remains nearly constant throughout adult life (Trotter, '51; Lasker, '53) there is a hint that the increases in skinfold thickness in group IV accompany a difference in body type which is not due to age progression.

To determine whether the present findings have relevance for human populations in general and for the question of change with age in particular, we may review the literature on age differences in height and weight. To the extent that our data for these measurements is comparable to those of other studies of males of advanced age, we may postulate that our findings for skinfold thickness can also be extended to such other situations.

Most previous studies of adult men show a progressive decrease in stature beginning at various ages (Pfitzer, 1899; Trotter, '51; Hooten and Dupertius, '51; Lasker, '53; Goldstein, as analyzed by Lasker, '53; and Pett and Ogilvie, '56). In some other studies no decrease in stature with age was noted (Lélut, according to Hrdlička, '36; Lantin, '35; and Coon, '50). In the one longitudinal study of adults, however, Büchi demonstrated that the group of adults aged 47-55 years showed a slight decrease in stature when they were remeasured 9 years later.

Few studies plot the weight of elderly men. Those which do either show a tendency to lighter average weights in the oldest age groups (Hooten and Dupertius, '51; Pett and Ogilvie, '56) or show no significant change (Lantin, '35; and Goldstein's data analyzed by Lasker, '53). The present series shows a decrease in stature but no appreciable age differences in weight.

In one previous study of skinfold thickness in the elderly, Pett and Ogilvie ('56) show a decrease in skinfold thickness with age especially in the males.

Unlike the present series, a random sample of the Canadian male population shows a decrease in weight and skinfold with age. This leaves open the question of whether in the popu-

lation sampled at Wayne County General Hospital, the younger individuals were differentially selected for some factor which might make for thin subcutaneous fat and hence for light weight. We have no evidence of any such factor. There is no reason to believe that one age group suffers more illness than another.

TABLE 3

Mean height, weight and skinfold thickness of the back of the arm of Canadian men in different age groups (Pett and Ogilvie, '56)

	AGE IN YEARS				
	30-34	35-44	45-54	55-64	65 and over
Mean height (mm)	1727	1714	1699	1676	1664
Mean weight (kg)	75.7	75.7	74.4	73.0	70.3
Mean skinfold (mm)					
Back of arm	8.2	7.7	7.5	6.9	5.6

In answers to our question concerning customary weight, of those who responded, 62% of those under 65 years of age said they formerly weighed more whereas 54% of those over 65 years old reported a loss of weight. The difference is not statistically significant by the X^2 test. The older individuals have probably been in the hospital longer, on the average than the younger ones, but in view of the reported loss of weight in such a high proportion of individuals, presumably since they entered the hospital, it is difficult to see how the newly admitted could be selectively lighter in weight.

On the other hand, the large number (50% of all individuals) who report loss of weight and the function of the hospital as a home for the indigent suggest that our findings may be particularly applicable to poor and therefore poorly nourished segments of the population. The actual diet of the "patients" at the hospital is apparently adequate, but some "patients" complain that it is not appetizing. In any case, the average weights are small by contrast with those of the populations of Canada (Pett and Ogilvie, '56), Ireland

(Hooton and Dupertius, '51) and the United States (Shepherd, 1899).

Our study indicates no noteworthy change with age in skinfold thickness. There are also no significant age differences in weight, but as many subjects report a previous loss of weight, this finding suggests that where subcutaneous fat is, on the average, already somewhat sparse in men of middle age, there is no further decrease as a result of advancing age.

SUMMARY

A survey of skinfold thickness of elderly white male ambulatory "patients" in a county institution for the indigent reveals no significant age trends. Although stature of those past 65 years of age is shorter than those 40 to 65 years of age, there is no significant age trend in tibial length or body weight. In this group, already light in weight in middle age, there is no decline in amount of subcutaneous fat in old age.

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A METHOD FOR REDUCING NON-SPECIFIC REACTIONS IN THE TYPING OF HUMAN SKELETAL MATERIAL ¹

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In view of the increasing interest in the problems of blood typing skeletal material from archaeological horizons, the following report on a technical improvement is presented prior to the actual analysis of results as correlated with cultural horizons. The present report forms part of a larger research project concerning the cultural, physical, and ecological relationships of prehistoric Indian groups inhabiting Delaware County, Oklahoma, covering a time span of approximately 7000 years.

Of immediate concern in blood typing bone is the problem of excluding the effects of non-specific absorption of final results. Non-specific absorption actually includes more than one process. Dry and finely divided substances have the capacity to adsorb substances from solution and such action may correctly be termed non-specific. In postulating the presence of blood group substances in bones buried in soil for varying amounts of time, the possible presence of cross-reacting substances must also be considered (Boyd, '56). Absorption by cross-reacting substances is not actually non-specific but conforms to definite patterns. Cross reactions occur between anti-A and B and blood group-like substances in plants and animals. Human bone containing the remains of Forssman positive

¹ This investigation is being supported by a research grant from the National Science Foundation (G 3923) and by the Wisconsin Alumni Research Foundation.

plants and animals might possibly react with anti-A without the bone containing human A substance. Gutierrez ('49) has raised the question of cross-reactions between the Forssman antigens and anti-A as being responsible for the large number of Type A reactions found on blood typing skeletal material from Monte Alban, Mexico. Soil samples from the area all inhibited anti-A without affecting anti-B. Data on living populations did not support the thesis of a high A frequency for archaeological horizons. These same strictures may also apply to Tepexpan man (Laughlin, '49), however type A was found in Prehistoric Oklahoma groups and apparently was present at an early date.

Lack of agglutination of red cells by sera absorbed with cancellous bone does not always indicate either absorption or adsorption. In testing the Oklahoma skeletal material it was found after absorption that in 10 of 89 samples, saline diluted anti-A and B had lost the capacity to agglutinate appropriate type red cells. By removing and washing the test red cells, a blocking effect was observed when unabsorbed sera were added. An unidentified substance in the sample was inhibiting agglutination but not combination. Several soil samples from the same area also gave this effect. Isotonic phosphate buffer used in place of saline as the diluent only partially eliminated the difficulty, that is, pH fluctuations were not entirely responsible. Thorough washing of bone samples is advisable to remove soluble foreign material. Blood group substances present in cancellous tissue obtained from earth burials can safely be presumed to be of the water insoluble form since the leaching action of ground water would have removed all of the water soluble form.

The most satisfactory method of minimizing the above difficulties was the substitution of human serum, from which all antibodies had been removed, as a diluent in place of saline. Type AB non-secretor serum would be the most satisfactory but such individuals are not common and in view of the large volumes needed, low titered A and B sera were used. Antibodies were removed by absorption with washed A₁, A₂ and B

cells until no agglutination was observed at either 20°C or 4°C. Type AB secretor serum, while not usually requiring absorption of antibodies, often contains enough A and B substances to make it unsuitable. In practice, absorbed or non-reactive A serum was used to dilute anti-B and B non-reactive serum was used to dilute anti-A. All sera used as diluents were checked for the presence of immune antibodies.

In testing 8 known type bone samples (3A₁, 1A₂, 30 and 1B), the only noticeable effect on final results by using non-reactive serum diluent was an extension of time needed for specific absorption. The optimum period for absorption was extended to 36 hours as against 24 hours for saline diluted sera. The aforementioned "non-specific" effects were not encountered with the known type specimens.

TABLE 1

Blood types of 39 prehistoric Oklahoma Indian skeletons

Phenotype

DILUENT	NUMBER				PERCENT			
	O ¹	A	B	AB	O	A	B	AB
Saline	27	41	3	18	30.33	46.06	3.38	20.22
Serum	71	18	0	0	79.78	20.22	0	0

¹ No reaction.

Saline diluent gave very different results than non-reactive serum diluent (table 1).

Only a partial answer can be given at this time as to the mode of action of non-reactive serum. It does act as a buffer and does serve to eliminate the so-called blocking effect. A and B antibodies diluted with serum remain stable over long periods of time, whereas activity progressively falls in typing sera diluted with saline.

The technique as used in the present research is presented below in outline form. It differs very little from that devised by Boyd ('39) and Candela ('39).

1. Wash bone in distilled water and let dry.
2. Weigh out two samples of 0.2 g.

3. Add 0.6 ml of anti-A diluted with non-reactive serum to one sample.
4. Add 0.6 ml similarly diluted anti-B to the second sample. The appropriate anti-body dilution is determined by selection of the dilution in the third tube back from the end-point.
5. Mix and let stand for 36 hours in the refrigerator.
6. Centrifuge and remove supernatant absorbed sera.
7. Retitrate using non-reactive serum as the diluent.
8. To each tube add one drop of a 2% suspension of appropriate type red cells suspended in non-reactive serum.
9. Centrifuge at 2000 rpm for 2 minutes.
10. Shake tubes vigorously. Positive reactions will not shake out. Interpretation is the same as in Boyd and Candela.

As to the detection of type O, anti-O is not routinely available, therefore an O reaction remains as indefinite as before. It has been suggested (Mourant, '54) that anti-H be used as a substitute for anti-O. Information collected in our laboratory indicates that such a substitution could lead to misleading determinations. One family has been studied in which the red cells of type O individuals contain less H antigen than that found on type A₂ red cells. Six families have been studied in which the cells of type B individuals contain as much H antigen as do type A₂ cells.

As yet, the results obtained from typing human cancellous tissue give only presumptive evidence of blood type. Such results cannot be removed to a more positive category until a more objective test is devised. In the future, the possibility of a chemical extraction and partial purification of the blood group substances will be attempted.

ACKNOWLEDGMENT

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COMMENTS AND COMMUNICATIONS

ERUPTION OF DECIDUOUS TEETH IN KOREAN AND AMERICAN INFANTS

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Yun ('57) reported in this JOURNAL an investigation on age of eruption of deciduous teeth in Korean rural children. The report has both descriptive and comparative contents. Its descriptive aspect is a solid contribution to knowledge on the physical development of Korean children.

The present communication relates to the comparative portion of Yun's paper. It is stated: "When one compares the status of eruption of the primary teeth in Korean and American babies, the teeth erupted in the early months, such as the central incisors, lateral incisors, and first molars, appear two to three months later in Korean infants." A re-examination of this generalization will show the inadvisability of uncritical acceptance and inclusion of the generalization in anthropological lectures or writings on comparative odontology.

It appears that Yun, lacking access to original reports of research on eruption of the deciduous teeth in American infants, depended upon a secondary source. Regrettably, the figures obtained from this source were unrepresentative of American research on deciduous tooth eruption.

Yun's data were collected 1953-54 in the Korean province of Chulla-Book-Do, the subjects were "presumably normal . . . breast fed . . . not on any extra vitamin A, D, and C." Analysis was made "without regard to sex" and dealt with "eruption status on the left side only." The report lists the percentage of children with particular teeth erupted at successive postnatal ages.

From a paper by Sandler ('44) one may derive fully comparable percentages at corresponding ages for an American sample. Sandler's data were amassed 1941-42 at Brooklyn, New York, on "white children of fairly low economic status but under regular nutritional and medical supervision."

Fully comparable percentages at four ages also may be drawn from an investigation by Doering and Allen ('42) on white infants residing in the vicinity of Boston, Massachusetts. These data were accumulated 1930-41 on a "middle class" group of "clinically normal" infants reared under pediatric guidance.

Table 1 places in juxtaposition findings from the three studies. Each percentage column for a given tooth contains values that are as similar

TABLE 1
*Percentage of deciduous tooth eruption among children of both sexes
grouped according to postnatal age in months*

INVESTIGATION	%	AGE	%	AGE	%	AGE	%	AGE
Lower left central incisor								
Sandler ('44) ¹	18	6	49	7-8	73	9	97	13
Doering and Allen ('42)	19	6			76	9	97	12
Yun ('57)	16	5	47	7-8	70	10	95	13
Upper left central incisor								
Sandler ('44)	4	6	48	9	77	11	91	12
Doering and Allen ('42)	1	6	48	9			89	12
Yun ('57)	4	4	55	10	81	12	90	13
Upper left lateral incisor								
Sandler ('44)	22	9	68	12	83	14-15	98	16
Doering and Allen ('42)	23	9	68	12			97	18
Yun ('57)	21	9	63	13	88	14-15	98	16
Lower left lateral incisor								
Sandler ('44)	8	9	38	11	76	15	95	18-19
Doering and Allen ('42)	9	9	35	12			94	18
Yun ('57)	6	6	39	12	80	14	95	16
Upper left first molar								
Sandler ('44)	5	12	38	14	76	16-17	83	17-18
Doering and Allen ('42)	2	12					83	18
Yun ('57)	5	8-9	35	14-15	74	18-19	81	20-21
Lower left first molar								
Sandler ('44)	5	12	32	14-15	71	16-17	82	18
Doering and Allen ('42)	2	12					82	18
Yun ('57)	6	8-9	36	14-15	70	18-19	82	20-21

¹ The N's vary between 43 and 185 for Sandler (American infants), between 241 and 270 for Doering and Allen (American infants), between 37 and 137 for Yun (Korean infants).

as the studies afford. The ages at which specific percentages were obtained are shown in the adjacent column on the right.

Examination of the findings brought together in Table 1 reveals the untenability of the claim that deciduous incisor and first molar teeth erupt "two to three months later in Korean infants" than in American infants. A more defensible inference, based on the Yun report and on the total available information for American infants (Robinow, Richards and Anderson, '42; Meredith, '46, '51; Ferguson, Scott and Bakwin, '57), is as follows: If a systematic difference exists between Korean infants and American infants in average age of deciduous tooth eruption, the difference probably does not exceed one month for any of the six teeth under consideration. In the present state of knowledge this may be taken as a tentative substitute for Yun's generalization.

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REVIEW

THE ALEUT DENTITION: A Correlative Study of Dental Characteristics in an Eskimoid People. By Coenraad F. A. Moorrees. Pp. + × 196, \$4.50. Harvard University Press, Cambridge. 1957.

The appearance of this monograph signals the fact that we now have more comprehensive knowledge of Eskimoid dentition than of any other racial group. Along with Pedersen's thorough study of the Greenland Eskimo, *The Aleut Dentition* provides first-rate comparative material for both northern approaches to the North American continent. Moorrees continually points out the need for odontological studies of other populations. Certainly the lack of modern surveys in this field has rendered less meaningful both Moorrees' and Pedersen's excellent coverage.

The 1948 summer expedition of the Peabody Museum of Harvard University to the Aleutian Islands was the occasion for the collection of measurements, observations, and dental casts upon which Moorrees based his study. The expedition found that of 1200 surviving Aleuts only 156 presently inhabit the Aleutian Islands. These Aleuts proper live in two villages, one on Umnak Island, the other on Atka Island. According to an earlier report by Laughlin, the Atka Islanders, or Western Aleuts, represent the survivors of a Paleo-Aleut population which migrated from the North American mainland some 4000 years ago. The Umnak people, or Eastern Aleuts, are the remnants of a much later immigration which absorbed the Paleo-Aleuts except for those on the westernmost islands. Laughlin considered both Eastern and Western Aleuts to be separate breeding isolates, basing his conclusions primarily upon differences between the two in stature, cephalic index, frequencies of genes for the M-N blood types and the Rh subtypes, and in certain odontologic traits.

We mention these hypotheses by Laughlin because it is to them that Moorrees orients the major portion of his work on dentition. In the second of 9 chapters in the book, Moorrees describes his objectives. They are:

1. To determine whether Aleut dentition is typically Mongoloid. Moorrees considers the basic Mongoloid pattern to consist primarily of marked shovel-shaped incisors, relatively small differences between the mesiodistal crown diameters of the maxillary central and lateral

incisors, a very low incidence of Carabelli's cusp, and a relatively high frequency of torus mandibularis.

2. To "verify the presumed differences between two closely genetically related Aleut populations." Moorrees points out that Laughlin was handicapped by the small size of the two groups to the point where "he was unable to establish the statistical validity of the majority of these differences." The dentition offers the advantage, the author claims, of presenting a large number of "independent" (sic) characteristics. The basic difficulty—that of small numbers—remains, however, and constantly perplexes the author (pp. 10, 18, 26, 35, 46, 47, 50, 86, 107, 118, 119).

3. To "evaluate differences in developmental patterns between Aleuts and Whites." This would be done by a study of tooth emergence.

4. To "obtain some information on the genetic origin and mode of inheritance of a type of malocclusion (viz. Class III) prevalent in the Aleut." This could be done, Moorrees claims, because the family relationships were known.

5. To "study the effect of environment on the incidence of dental disease." The opportunity to do this is offered by the fact that the environment within the last 50 years on the Aleutian Islands has changed whereas "the genetic factors have been much more stable during this period."

Space limitations prohibit a discussion of the many interesting and thorough observations made by Moorrees on the Aleutian dentition. They are subsumed under the heading Dietary, Morphological Characteristics, Odontometry, Tooth Emergence, Tooth Position and Occlusion, and Dental Disease. There is also an appendix presenting many tables of comparative odontometric data of different populations. There is no question in the reviewer's mind that Moorrees has made an important and significant contribution to the literature in this field. However, there are certain aspects of this work which must be challenged.

Of the 156 native inhabitants of the Aleutians, some were not available for study during the summer of 1948 for a number of reasons. Nevertheless, Moorrees obtained casts of the permanent dentition of 94 individuals, 45 of whom were Eastern Aleuts and 32 Western Aleuts. The remaining 17 were "intermixtures." Throughout the text, as mentioned above, the author calls attention to the fact that this small sample (rendered even smaller when broken into various subgroups) does not permit the derivation of reliable statistics. We are tempted to ask how much larger the "sample" should be in order to have one of sufficient size. Since his "sample" consists of 60% of

the living Aleutian inhabitants and represents an even higher percentage of those with permanent dentitions, the addition of a few more individuals would give us the entire population of the islands. To what mythical universe would a "sample" consisting of all living inhabitants of the Aleutians apply?

If, indeed, the Eastern and Western Aleuts constitute two distinct breeding isolates—and this phenomenon can only be positively established by historical data, not by such questionably genetic traits as cephalic index and stature—then the question is posed: What would be the genetic consequences in small populations such as the Eastern and Western Aleuts? Clearly the amount of divergence from an original basic gene pool expressed in differential gene frequencies would be a function of the time elapsed since the original split. Time is not the only factor, however. The amount and degree of familial inbreeding within each population plays a significant role in establishing degree of homogeneity as well as divergence. Moorrees states at the conclusion of chapter 5 (p. 76): "It should also be remembered that in this study the method of grouping for Eastern and Western Aleuts may have affected the findings, since only very accurate genealogic records on several generations could ensure proper ethnic classification of the living Aleut population." This seems a rather belated recognition that the data obtained on this expedition do not lend themselves to the sort of analysis Moorrees is intent upon—namely, the establishment of East-West differences to verify the hypothesis of separate breeding isolates. Fortunately, however, Moorrees also "lumps" his East-West observations so that we always have a picture of the Aleuts as a whole.

The many involved and challenging assumptions tacit in the use of such terms as "basic pattern," "intensification," "simplification," and "retention," found throughout the monograph, wave, in the reviewer's mind, the red flag of caution. We seem to detect at times the shades of orthogenesis slipping in through the back door. We wonder if two points on a continuum really established a "trend."

The reviewer was particularly interested in the small section on occlusion and malocclusion (pp. 116-121). We are unable to accept the author's statement that "because of tooth wear the mandible has moved slightly forward from a . . . scissor bite to an . . . edge-to-edge relationship." This implies a relocation of the mandible due to tooth wear which is incompatible with our knowledge of temporo-mandibular joint physiology. He further implies a causal relationship between tobacco chewing and edge-to-edge bite which is unsupported by experimental studies. His morphologic description of Class III facial patterns implies a degree of similarity not observable in any other

previously studied population. Other studies have shown marked variation of facial patterns accompanying similar Class III malocclusions. Angle's classification, which the author employs, is based purely on teeth. The supporting evidence for facial pattern is not provided by Moorrees. We wonder how "atypical development of the mandible" is diagnosed without the establishment of norms for the Aleut population and without the use of roentgenographic cephalometry.

There are many admirable features of this monograph which the reader will discover upon perusal. We suspect some will like, others will object to the placement of all 41 figures in advance of the textual material which refers to them. All will agree that they are pertinent. This monograph will be a valuable reference for future odontologic studies of populations, even though the author's announced aims have not been fully realized. He has demonstrated that the Aleut dentition is essentially a Mongoloid one (we suspected this previously) and that differences exist between the Eastern and Western Aleuts. He has not contributed anything further to our knowledge of the genetics of malocclusion or to the effect of environment on dental disease, nor was he able to evaluate differences in developmental patterns between Aleuts and Whites.

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BLOOD GROUPS IN PYGMIES OF THE WISSELLAKES IN NETHERLANDS NEW GUINEA

With Anthropological Notes

By H. J. T. BIJLMER, *University of Amsterdam*

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In several inaccessible areas of the islands extending from the south east of Asia are found groups of natives characterized by their short stature, close-curved or frizzy hair, dark pigmented skin and other negroid features. Groups of these pygmies who in this area are generally referred to as Negritos (Spanish—little negro) have been found in the Philippines, the Andaman islands, the Malay Peninsula, southern Siam and New Guinea. They and the African pygmy tribes of the upper Congo are said to belong to the same basic stock (Stirling, '43) which is believed to have contributed genetically to many of the dark-skinned peoples throughout the world.

In discussing this relationship Polunin and Sneath ('53) comment "The physical similarities between the Asian Negritos and the African pygmies and Negroes and their geographical isolation from one another make comparative studies of these two people of obvious interest. The similarity may be due to common ancestry or to parallel evolution which might have occurred by chance or by natural selection favoring the same useful physical characteristics in different races with similar environments."

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Irrespective of any African-Asian relationship it appears to be generally accepted that the Negritos are derived from isolated remnants of a very early migration from Asia to the south-east and the belief has been expressed that they and the Australian aborigines represent earlier stages in human evolution than do most of the other peoples still living in the world today. This belief is supported by some anthropometry and by evidence of the primitive cultural development of both groups. However some very important characters, amongst which may be cited the tendency to brachycephaly in the Negrito and the hair form and other characters of the Australian, are major difficulties in the way of unreserved acceptance of this evolutionary theory.

According to Taylor ('45) the first migration from south-east Asia consisted of Negritos who were later driven into forested highlands by succeeding migrations of more advanced peoples. In this way he explained the existence of Negrito groups in widely separated and inaccessible places. Actually they are found almost invariably in tropical forested highlands.

Birdsell ('48) in advancing his theory of the tri-hybrid origin of the Australian aborigines has referred to the Negritos as being the first identifiable migrants to Australia and New Guinea. He states that the Negritos subsequently mixed with two later migrating elements to form the present-day native populations of both countries. He claims that the phenotypic differences between the two groups are due to a predominance of the Negrito element in New Guinea together with small recent addition of Mongoloid genes in some areas in contrast to the predominating Murrayian and Carpentarian genes in the Australian with only a minority of Negritic genes. The extinct Tasmanian, he considered, was dihybrid with Negritic and Murrayian elements only. Birdsell further states that "In the interior highland plateaus of New Guinea and in the interiors of such larger Melanesian islands as New Britain and New Caledonia the populations are quite clearly dihybrid,

consisting of a predominant Negritic element to which has been added a minority of Murrayian genes."

Whether the phenotypic differences observable amongst the long-isolated Australian aborigines are the result of known biological processes, (Abbie, '51), or of hybridization (Birdsell loc. cit.) it would seem that hybridization would be the most important factor in determining types in New Guinea except perhaps in the interior mountains where dense vegetation and other geographical features provide a barrier protecting the earlier occupants from later migrating elements. It is in these parts that the pygmy groups have been found.

Lack of data for Negritos has hindered evaluation of blood grouping results obtained for other populations believed to have an appreciable Negrito component.

Polunin and Sneath ('53) have presented the results of a comprehensive survey of the blood groups of Malayan Negritos. They have also summarized previously published work on Negritos covering the A-B-O groups, namely that of Grove ('26) for the Philippines and Schebesta ('52) for the Philippines and Malaya. A few results obtained by Gates ('40) for Andaman Island Negritos were also given.

Lehmann and Ikin (Lehmann, '54) investigated both blood groups and the sickle-cell trait in Negritos from the Andaman Islands.

A group of natives said to be of reasonably "pure" Negrito stock was known to live in the Wissellakes district of Dutch New Guinea. The present paper reports the results of a blood grouping survey carried out in December, 1950, on the Kapaukoe tribe of that area. According to Birdsell this group is basically Negritic modified by an obvious Murrayian element. A discussion of the genetic relationships of various Papuan and Melanesian groups with particular reference to the mountain Papuans has been given by Semple, Simmons, Graydon, Randmae and Jamieson ('56).

To appreciate better the relationships and general characteristics of the population sample, we sought and were most fortunate in obtaining an authoritative contribution on their

cultural and physical anthropology by Dr. H. J. T. Bijlmer, Anthropologist — Geneticist of the University of Amsterdam. We are greatly indebted to him for the following valuable description based on his own first hand knowledge of this people and their neighboring groups:

*Anthropology of the Mountain Papuans of the
Wissellakes in Central New Guinea*

by

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University of Amsterdam

The Papuans of the plains, aborning the Central mountain ranges of the Dutch Western half of New Guinea and especially those to the South, in the Coastal plain from Mimika to the border of Australian Territory, are a tall, muscular and fierce folk of cannibals and head-hunters, mostly leading a nomadic life, settling down temporarily at places where the sago-palms provide them with food for many months in advance, then returning to the Coast with its abundant supply of fish and edible molluscs.

In the interior, with its rough mountains, the Papuan is shortest, often near or even below the pygmy standard. But the so-called pygmy-Papuan has learned to adopt the sedentary life of a tiller of soil and a tender of pigs. Not that the men of the coast are deprived of gardens, but these are often small and badly looked after, at least in spots where sago and fish are easily procured.

Whether there is any difference in race between the tall Papuans of the coastal regions and the pygmoid ones of the mountainous interior is as yet unsolved. There is indeed a vast divergence in type among the Papuans: faces of the utmost rudeness and ugliness alternate with countenances of rather noble cut. It is not that the primitive-looking are concentrated in definite areas. On my repeated visits I received the impression that the Papuan on the whole is rather uniform in type, but that this type is extremely variegated in some respects. In my opinion the complete similarity in hair form and hair color, the great resemblance in color of skin and the fundamental likeness between Papuan faces are sufficient grounds for regarding all kinds of Papuans as varieties of the same race. Moreover, in both the tall and small variety beards are often seen, and, what is more conclusive, the semitic type, so conspicuous of the Papuan of the coast, is not less common in the pygmoid tribes of the furthest interior.

Thus in my opinion there is some difficulty in discerning Palaeo-melanides and Neo-melanides, denominations that von Eickstedt ap-

plies respectively to the shorter-set, roughly faced type, and the taller type with more noble countenances. His conception implies a primitive type, superimposed by an advanced one, i.e., a "contact form" derived from a mixture with some neighboring people. However the primitive in New Guinea is so inextricably mixed up with the progressive that it seems to me that von Eickstedt's two forms are natural variations of the same substratum. As mentioned before, the real Papuan is in his fundamental race characteristics — dark color, kinky hair, and utterly un-mongolic cut of face, — so true to type that mixture from outside, where lank or wavy hair, lighter skin-color and mongoloid traits prevail, is highly improbable indeed. Where mixture is known to have occurred, i.e., along the west and south east coasts and in many of the Melanesian Isles, the results are obvious: wavy hair, lighter skin shades and Mongolian eyes crop up in a noticeable degree. So these "Melanesians" of the coastal regions of the islands, which geographically comprise Melanesia, may better be considered as the "contactform" of the Papuan race, and the latter as being confined to New Guinea and the interior of the bigger Melanesian islands. This race is old and primitive indeed, but nevertheless shows a variability in which an inclination towards evolution in nobler forms is coming to the fore.

The Papuans of the interior are still living in the stone age; in 1920 our expedition met with tribes who were totally ignorant of iron. Their only large tool was a stone axe, their weapon the bow and arrow. They did not know how to weave, penis-gourds for the men and string or fiber skirts for the women being their only clothing. They do not manufacture pottery; they make no use of vessels or jars. Water is fetched and kept in bamboo, solids in knitted bags.

So here we are rather at the bottom of civilization. To have made the acquaintance of these people, representing the neolithic times of our own prehistory, was certainly an achievement of our expeditions of the utmost importance. Completely enclosed in their inaccessible highlands, with scarcely any contact with the tribes of the coast, who in their turn dared not penetrate into the mountains, bound as they were to the waters of rivers and sea, these mountain-Papuans had been kept in a primeval state as nowhere else on earth.

Yet it should not be overlooked that these people are beyond the stage of mere hunting and collecting. They rank above Australians, Bushmen, Veddas and several jungle tribes of India and America. They practice agriculture; besides the cone-roofed hut they know the square and the oblong one, next to the spear and club the bow and arrow; they chew sirih and grow and smoke tobacco; they make fire by sawing a rattan string along the bifurcated branch with some combustible material in the cleft; they construct fine suspension-bridges.

It is not astonishing that they are ignorant of weaving, this art not being indigenous in Oceania. But their isolated life is demonstrated in the lack of pottery, this being well known in Melanesia. And they are well nigh the only people who over an extensive area have preserved the use of the penis-sheath, this remarkable attribute of manliness which is held to be a characteristic of the totem culture and which is found elsewhere only in small communities scattered in the forests of Africa and America.

Moreover, it is not only that their own cultural stage is one without metals, pottery and weaving, the essential point is that there are, or at least on my arrival were vast areas where not a scrap of iron, a shred of cotton or a single potsherd from elsewhere has found their way. Civilization has not yet crossed the border of this people's country and has spared them its good and evil until now. They were still in neolithic times and more primitively so than the ancient lake-dwellers of Switzerland who, as a matter of fact, were acquainted with the arts of weaving and potmaking, and knew the cultivation of corn and the use of cattle.

Physical, Psychical and Social Condition

The physical condition was satisfactory. We met with a breed of well built, healthy-looking people. Their short stature was by no means accounted for by malnutrition and it did not look as if chronic diseases prevailed. A difference could be noted between the mountain people and those of the coast who although tall and muscular paid a heavy toll to malaria and were sorely afflicted with framboesia, in consequence of which cripples were common, miserable looking individuals often seen and skin diseases numerous.

It is obvious that the health of primitive peoples is largely dependent on the healthiness of the country they inhabit. Nature controls the situation. If conditions are favorable as is the case in the mountains, the discoverer meets with a sound breed of man; natural selection looks after the demolition of the weak and sick.

It is of far greater interest to know the psychical condition of our stone age people. And it is on this point that we encountered facts of quite another kind than we had expected. One would expect to meet with folk who held the balance between children and wild beasts; silly and easily frightened on one side and rude, cruel and aggressive on the other. Nothing is farther from the truth. From the first moment that we met these pygmy-Papuans who had never seen white men, we perceived that we had to deal with men like ourselves, and that after the first alarm had been allayed, we were frankly considered as fellow-men, creatures of the same standing as their own. This was the most astonishing discovery of our 1920 expedition.

In the midst of an inaccessible wilderness, in the darkness of neolithic times, we met with comrades. We were made to sit down at their hearth, we were offered bananas to eat and sugarcane to suck; the men deliberated earnestly, the women laughed and were delighted with our attention, the children with our gifts. The latter, who were urged to greet the newcomers, were enjoined to be friendly, and so our company was soon on easy terms with our prehistoric hosts.

Their attire was of the simplest, a long grown calabash as a penis-sheath for the men, fastened in an upward position with a string round the loins and covering nothing but the virile member; a skirt of loose hanging strings, reaching from the hips to the knees for the women. Their adornment was likewise of a primitive kind: strings of seeds, teeth, or small vertebrae, bracelets of plaited fiber, some bright-colored feathers or bits of fur.

The main implement was the stone-axe, carried lightly on the right shoulder. Moreover, polished stones were used as knives, and there were further all sorts of small bone implements. We observed an almost entire lack of furniture and utensils. The latter are of no use, for cooking and baking are done between hot stones in the earth, or in the hot ashes of the fire; pottery is unknown, likewise weaving, and the only pieces of manufacture are knitted bags, universally worn by men and women, and varying from a few inches long to half a meter or more. No attempt at decoration was to be seen on the walls of the huts, though these had been neatly built of lopped boards and only a few carvings had been made on the arrows.

So the mode of living of these people was perfectly plain. But it was not this that struck us most; in fact we scarcely noticed it at first. This was because we felt immediately at home. Possibly the fashion of greeting, a peculiar pulling of the knuckles, followed by a cordial shaking hands charmed us and a further acquaintance brought no disappointment. Distrust and greed remained completely in the background. The manners of this people were in several respects like our own; in their trade that was established immediately, in their moods of friendliness and anger, eagerness and fear, in their keen interest or anxious anticipation. Also in the relation between men and women, and in the attitude of parents to children, they behaved in ways familiar to us. Do not imagine that the wives are merely the slaves of their husbands. I have repeatedly heard the former express their opinion so vigorously that it left me no doubt as to their reasonable position. Both men and women carry the children, or loads of turnips and sugarcane, and we saw men and women together building a house.

We got the impression that the psychical life of the Mountain-Papuan rises considerably above that of the people of the coast. The latter may not be denied a certain cleverness but a deeper interest is totally

absent. The Coast Papuans can count up to three and then follows "many." The Mountain-Papuans on the other hand showed a striking desire for knowledge. For example, they inquired about the course of the sun in the country of the white men. This surprised Father Tillemans the more as his stories about the sun, moon and stars used not to rouse the slightest interest among the people of the coast. The children of the Mountain-Papuans began to count the pages of our diaries as fast as they could; they counted patiently in the decimal system up to over a hundred!

Physical description

In 1939-40 a large scientific expedition sponsored by the Royal Netherlands Geographical Society, and put under the leadership of the geographer-ethnologist Ch.le Roux, set out for the Wissellakes. The Anthropologist, Dr. D. Brouwer, assembled a great many anthropological data, including blood groups, but all were lost in the War. I, myself, had visited the region a few years earlier (1936), and though not reaching the Lakes that had yet to be discovered (1937) met with the tribes that later proved to be the inhabitants of their borders and had amply the opportunity to investigate them. So the following data refer to the people of the Lakes and the adjacent valleys.

The stature is, as may be expected for the mountain folk of Western N. Guinea, small. We are here in the close neighborhood of the famous Tapiro-Pygmyies discovered by Wollaston (English Mimica expedition 1910). Wollaston denotes the stature of the latter as 146.9 cm; I was able, a quarter of a century afterwards (1935) to examine a larger number of these pygmyies, and found 148.9 cm. They were of exactly the same tribe as that seen by Wollaston and some of them remembered this first contact with the whites.

The Tapiro Pygmyies are as yet the smallest Papuans found in the central part of New Guinea; nevertheless several expeditions have proved that all the valleys of the Central Mountains are inhabited by a similar type of Mountain Papuan pygmoids, the stature of whom averages 152-155 cm. The average of 300 Mountain Papuans of the Lake region amounted to 152.8 cm for the men and 143.3 for the women. A conspicuous peculiarity is, however, that amongst the Ekari, which is the name of these pygmoid people who form the bulk of the population round the Lakes, a tribe of higher stature is living (± 160 cm), the Moni. They are real Mountain Papuans indeed; attire and customs are the same and their villages are distributed between those of the Ekari. Their social position, however, is a higher one, as by some mysterious reason they feel superior to the Ekari's.

The headform of the mountain folk is mesocephalic in sharp contrast to the utterly dolichocephalic headform of most of the lowland Papuans. Relevant average cephalic indices are — 300 men from the neighborhood of the Lakes, 79.9; 20 women, 79.0; 9 Moni men, 77.7; 50 Tapiro pygmies, 78.9; 26 female Tapiro pygmies, 80.0; in contrast to coastal Papuans of the nearest plains, 73.0. The cephalic index of 79.9 ensues from an average headlength of 181.4 mm and a headbreadth of 144.7 mm. The facial index of the Lake people (males) is about 81.0 in contrast to 88.0 for coastal Papuans — respectively euryprosope and leptoprosope. This euryprosopy is due to a relatively greater jugal breadth of the mountain people, not to shortness of the face. The nasal index is chamaerrhine for the Lakes and mesorrhine for the coast. So the Lake people, and the Mountain Papuans in general, have broader skulls, broader faces and broader noses than the coast Papuans.

The Mountain Papuans are not conspicuously different in color from the inhabitants of the coast; they are dark brown. The hair is uniformly woolly. Its color is black. As to the face, of all colored races not belonging to the Caucasian main stem the Papuan has the face which most approaches the European type. It seems to me that all European forms of face are fundamentally present; the semitic one too is common. Negroes and Mongolians have specialized in a direction divergent from the Whites; Papuans only seem to represent a primitive form of the type maintained for the Caucasians.

The eye-slit is horizontal and wide. Mongolian characteristics, so frequent in Indonesia and Polynesia, are practically completely absent. The nose-saddle often recedes abruptly below the forehead, but a torus frontalis seldom occurs; the superciliary arches are not heavier than with the European. The combination of deep-set eyes, large projecting nose and hardly pronounced jugal arches, particularly when a beard is present give an impression which is totally non-Mongolian and also differs from the Negro. It lies rather in the direction of Australians and Dravidians. The bridge from these two groups to the Caucasian race has been frequently built; it is easier there, since the gulf separating woolly hair from lank need not be passed.

MATERIALS AND METHODS

On the 8th and 11th December, 1950, blood and saliva samples were collected at Enarotol, 5700 ft. above sea level, from 200 Mountain Pauans of pygmy stature living in the Wissellakes District of Netherlands New Guinea. At the same time opportunity was taken to test the ability of the natives

to taste phenyl thiocarbamide. Owing to language barriers, the shyness of the natives and their reluctance to disclose their names to strangers, the following sequence was adopted for collection of samples and taste testing.

One of the local Government Administrators who knew both the language and names of individuals living in the area assembled the natives in groups of five and had them rinse their mouths thoroughly while he recorded their names, sex, district, tribe and genealogy and gave each an envelope carrying an identifying number. One assistant collected blood samples by finger puncture the usual attempt being made to perform this operation aseptically. No difficulty was experienced in this nor was any objection raised by the natives. As soon as 10 blood samples had been collected they were placed on ice in a Stanley jar where they remained until the end of the day when they were transferred to a kerosene refrigerator at the Mission to await shipment to Biak.

Immediately after each blood sample had been taken saliva was collected from the same individual by a second assistant. The saliva was steamed in a closed pan for about 40 minutes to sterilize it and destroy enzymes present.

Then followed the taste-test which was performed with test papers by the technique described by Simmons, Graydon, Semple and Taylor ('51) but in this case great difficulty was experienced in trying to make the natives understand what was required of them and also in interpreting their reactions.

One disadvantage of this test is that once a phenyl thiocarbamide-impregnated paper has been given to a taster repeat tests within 15 minutes or so are valueless. Delayed reactions also give trouble and may be the cause of incorrect classification if the subject is observed for too short a period. Some individuals who can taste nothing on first placing the impregnated test paper in their mouths, later experience bitter taste sensations which may persist for a considerable time. The greatest difficulty is in distinguishing the "weak taster" from the "non-taster." The reactions were faithfully recorded and one of us (S.F.) who actually performed or closely

supervised the field work interpreted the results and classified the individuals tested. One hundred natives were assembled on 8th December, the first day of testing and 60 on the second day, 11th December, but the total number was made up to 200 from natives working at the Agriculture Station and others attending a wedding feast nearby. In this area little malaria is seen, and there is no tropical ulcer but framboesia is rather common.

The blood samples were kept in a kerosene refrigerator until just before their shipment to Biak on 16th December. They were sent by air in ice-packed Stanley jars from Biak to Darwin and thence on to Melbourne where they arrived in fair condition on 21st December, 10-13 days after collection. They were tested immediately by methods which have been described by Simmons et al. ('51).

Of the 200 blood samples collected 61 had to be discarded because of lysis, but the remainder were in good condition and gave strong specific reactions with the test sera. There were 3 samples from Moni people included amongst the 139 tested and these have not been separated in the subsequent discussion.

Of the samples tested 50 were from females aged from 17 to 40 years and 89 were from males from 15 to 40 years of age.

RESULTS AND DISCUSSION

The results of the tests performed are summarized in table 1 which gives the number and percentage observed in each phenotype for all factors studied in this survey.

In table 2 gene frequencies calculated from the A-B-O, M-N-S and Rh results have been compared with those relating to certain other populations which may be relevant to ethnological discussion of the Papuan pygmies.

The A-B-O blood groups

Of the 139 samples tested for A-B-O groups 85 (61.2%) were of group O, 18 (12.9%) were of sub-group A₁, 34 (24.5%) were of group B and 2 (1.4%) were of sub-group A₁B. The

following gene frequencies have been calculated: $A = .075$, $B = .139$, $O = .786$.

A feature of the A-B-O frequencies is that the value of A is lower than has been reported for Negritos of Malaya, the Philippines or the Andaman Islands and also somewhat lower than that found in neighboring Papuan groups. The frequency of B is higher than that reported for other Negrito populations. However, in this case the value for the Wissel-lakes pygmies is similar to that observed in other mountain Papuans and Melanesian groups generally. It is interesting to observe that Schebesta in his series drawn from various Negrito tribes in the Philippines encountered one tribe with A-B-O frequencies fairly close to those found in the present survey. The Papuan pygmy has higher B and O frequencies and lower A frequencies than have been found in other Negrito groups so far investigated. On the other hand the combined figures of Jadin and Julien (Elsdon-Dew, '39) for African pygmies show substantially higher A and B and hence much lower O than is found in Negritos.

These differences do not support a supposed close relationship between Negritos and African pygmies.

Unfortunately the anthropological records of a survey carried out by Dr. D. Brouwer as part of the Royal Netherlands Geographic Society's expedition in 1939-40 were lost during the war. Dr. Brouwer, in a personal communication to Dr. Bijlmer, gave the following information on his blood grouping tests: Of 400 Moni people 55% were of group O, 30% group A, 13% group B; of 196 Ekari, who are identical with the Kapaukoe of this survey, 60% were of group O, 10% group A, 25% group B. Our results for A-B-O group of the Kapaukoe are very similar to Brouwer's for Ekari, but there is a reversal of the frequencies of A and B in the Moni people a taller race living in the same area but not included in our series.

The exceptionally low frequency of A found in this survey and by Brouwer cannot be attributed to relationship with neighboring groups or with other Negritos. It seems reasonable to assume that genetic drift in a small breeding popula-

tion may have been a major factor in producing this low frequency.

The presence of the B gene in substantial amount in the Negrito and its absence in the Australian aborigine except in the North where it is believed to have been recently acquired, do not support the theory that there is a large component of Negrito blood in the Australian.

No sample of sub-groups A_2 or A_2B was encountered. This is in line with the findings reported for Malayan and Andaman Negritos and other colored races of the Pacific area, but contrasts with the high relative frequency of A_2 to A_1 observed in the African Negro. The A_2 gene is evidently of very low incidence in the African Pygmy for Snoeck and Hubinont ('49) found no example of subgroup A_2 and one of subgroup A_2B in 94 Batswa pygmies of the Belgian Congo, and Allison, Ikin and Mourant ('54) did not encounter the subgroups in their small series of 33 Tswa pygmies. This is an outstanding point of distinction between the African pygmies and their Negro neighbors in whom the A_2/A_1 ratio is particularly high. The absence of A_2 in both Negritos and African pygmies favors the theory of a common origin for these two groups but other blood grouping evidence does not support this theory.

The M-N types. M-N tests were performed on 138 samples only one of which proved to be of type M, with 26 (18.8%) of type MN and 111 (80.4%) of type N giving gene frequencies, $m = .101$ and $n = .899$. In subsequent tests with anti-S serum only two samples out of 137 were agglutinated and both of these were of type N. The M-N results, exhibiting a low frequency of m , are very similar to those reported for some other Melanesian groups notably the coastal Papuans of the Daru-Kikori area of New Guinea, the primitive Bainings of New Britain and the Mountain Papuans of Chimbu-Mt. Hagen area of New Guinea. They are quite unlike those observed in African pygmy groups in which the frequency of m is high and similar to that of the Negro.

Polunin and Sneath ('53) found that the M-N distributions in Malayan Negritos and their neighbors the Senoi and Abor-

TABLE 1

Protocol of results in present survey

BLOOD GROUP SYSTEM	NUMBER TESTED	NUMBER AND PERCENTAGE IN EACH PHENOTYPE					
		A ₁ 18(12.9%)	A ₂ nil	B 34(24.5%)	A ₁ B 2(1.4%)	A ₂ B nil	
A-B-O	139	O 85(61.2%)	MMS nil	M _S Ns 26(19.0%)	N _S Ns 108 ¹ (78.8%)	MNS 2(1.5%)	
M-N-S	137	M _S M _S 1(.7%)	Rh ₁ Rh ₀ 7(5.1%)	Rh ₁ Rh ₂ 26(19.0%)	Rh ₂ 4(2.9%)		
Rh	137	Rh ₁ Rh ₁ 100(73.0%)	Le(a+) nil				
Lewis (Le ^a)	116	Le(a-) 116(100%)	Non-secretors nil				
A-B-H secretion	116	Secretors 116(100%)	P(---) 34(37%)	Fy(a---) 3(10%)			
P	91	P(+) 57(63%)	Weak tasters 12	Non-tasters 64			
Duffy (Fy ^a)	30	Fy(a+) 27(90%)					
Taste reaction to P.T.C.	178 ²	Tasters 50					

¹ One type N sample was not tested with anti-S serum; altogether 111 out of a total of 138 samples were of type N.² Fifty-two of the individuals tested could not be classified with confidence.

Blood group gene frequencies in various populations

POPULATION	AUTHORS	NO. TESTED	A	B	O	NO. TESTED	mS	ms	nS	ns	NO. TESTED	R ⁰	R ¹	R ²	R ²	r	r'
Papuan Pygmies Wisselakes N.G.	This survey	139	.075	.139	.786	137	0	.102	.007	.891	137	.030	.850	.119	0	0	0
Papuans, Central Highlands N.G.	Seiple et al. ('56)	485	.195	.159	.646	488	0	.036	.117	.847	485	.028	.892	.031	0	0	0
Papuans Coastal, East N.G.	Dunn et al. ('56)	1060	.134	.220	.646	1005	.013	.153	.101	.732	1034	.029	.905	.065	.001	0	0
Papuans (Chimbu, Central Highlands N.G.	Ivinskis et al. ('56)	864	.242	.159	.599	864	0	.025	.148	.827	864	.026	.895	.078	0	0	0
Papuans Coastal, Biak N.G.	Nijenhuis and van der Hoeven ('56)	183	.101	.120	.780	183	0	.265	.039	.696	183	.011	.929	.057	.003	0	0
Negritos Malaya	Polunin and Sneath ('53) ¹	493	.129	.104	.767	102	.090	.645	.047	.218	104	.269	.635	.097	0	0	0
Senoi Malaya	Polunin and Sneath ('53) ²	475	.060	.229	.711	69	.068	.649	.038	.245	101	.005	.926	.069	0	0	0
Aboriginal Malays	Polunin and Sneath ('53) ³	259	.119	.192	.688	107	.028	.766	0	.206	107	.019	.935	.037	.009	0	0
Negritos Philippines	Grove ('26) and Schebesta ('52)	650	.189	.084	.726												
Filipinos	Simmons and Gray- don ('45), Walsh et al. ('54)	856	.151	.166	.683	474	.012	.528	.023	.437	473	.066	.807	.109	.018	0	0
Negritos (Onges) Andaman Is.	Lehmann ('54)	52	.54	.08	.38	52	.10	.51	0	.39	52	0	.92	.08	0	0	0
African Pygmies Belgian Congo	Hubinont and Snoeck ('49) and Jadin, Julien and Gusinde ⁴	2557	.198	.249	.553	94	.468 (m)		.523 (n)		94	.630	.074	.194	0	.101	0
Negroes, Bantu Africa	Shapiro ('51 and '53)	6020	.190	.130	.680	205	.092	.488	.044	.376	600	.596	.047	.085	0	.214	.058

¹ Figures incorporate results of Schebesta ('52) for the A-B-O groups.² Figures incorporate results of Green ('49) and Schebesta ('52) for the A-B-O groups.³ Figures incorporate results of Green ('49) for the A-B-O groups.⁴ A-B-O figures are pooled results of Jadin, Julien and Gusinde quoted by Boyd, W. C., 1939 Blood Groups. *Tabulae Biologicae*, 17: 113-240.

iginal Malays were alike, and were characterized by a very high m frequency which is in contrast to the low m frequency of the Papuan pygmies. The $S(+)$ frequencies reported by these authors varied from less than 6% in the Aboriginal Malays to 25% in Malayan Negritos which is higher than the 1.5% found in the Papuan pygmies. In the small series of Onges of the Andaman Islands reported by Lehmann ('54) the M-N-S distribution which includes 19% S positives was not unlike that the Malayan Negritos. The low $S(+)$ frequency of the Papuan pygmies distinguishes them also from other mountain Papuans, and also from coastal Papuans who have appreciably higher frequencies of the ns gene. However, Nijenhuis and van der Hoeven ('56) report a very low S -positive frequency in Papuans of the Schouten Island area.

In general it may be said that the M-N distributions of these pygmy groups are similar to those of their own neighboring groups, and differ greatly from each other.

As the M-N frequencies found in all New Guinea groups and in the Australian aborigines are somewhat similar little can be inferred from them, which bears on the proportion of any Negrito component in the Australian. However, the absence of S in the Australian aborigine and the low S in the Papuan pygmy in contrast to the variable but higher S in other New Guinea groups might favor an appreciable Negrito component in the Australian, but this is difficult to reconcile with the absence of the B gene in Australia.

The Rh types. All of the 137 samples tested with anti-Rh type sera were Rh-positive, the phenotypes represented being Rh_1Rh_1 (CCDee)100(73.0%), Rh_1Rh_0 (CcDee)7(5.1%), Rh_1Rh_2 (CcDE)26(19.0%) and Rh_2 (ccDE)4(2.9%). To account for these phenotypes it is necessary to assume the presence of three genes R^1 , R^2 and either R^0 or r . As gene R^0 has been proved to occur in native peoples of the western Pacific area and gene r is of doubtful existence in "unmixed" natives of this area, we have preferred the former, although it should be remembered that the frequency given for R^0 is really the

sum of the frequencies of R^0 and r . Gene frequencies calculated on this basis are $R^0 = .030$, $R^1 = .850$ and $R^2 = .119$.

The differences between the Papuan pygmies, who have very high R^1 and low R^0 gene frequencies and the African pygmies who have high R^0 and low R^1 , are even more marked in the Rh system than in the M-N-S system. In these major differences each of these groups resemble their neighbors — the Papuan pygmies having frequencies similar to those found in other Papuans, and the African pygmies being similar to the Negroes. The gene r is present in both African groups, but absent in the Papuans.

Malayan Negritos have a fairly high frequency of R^0 which cannot be accounted for by admixture with neighboring peoples all of whom have low R^0 frequencies. In fact, the Rh frequencies found in Malayan Negritos are intermediate between those of the Papuan and African pygmies, and the high R^0 in the Malayan has been advanced as evidence of relationship between the Asian and African pygmies. It is difficult to reconcile this theory with the finding of an especially high incidence of the sickle-cell trait in the Africans, and its absence in the Malayan Negritos and also in the Andaman Islands Negritos, who, in addition, present the obstacle of a low R^0 incidence.

It would be of interest to know the M-N-S and Rh types of the Negritos of the Philippines particularly type Rh₀. The Filipinos have gene frequencies very different from those of the New Guinea pygmies and other Melanesians. One might expect m to be around .5 and R^1 to be about .8 for the Philippine Negritos. All efforts to date made by us to get Negrito samples out of the Philippines have failed.

A-B-H secretion and Lewis (Le^a) blood group. Tests were performed on 116 saliva samples to determine the A-B-H secretor status and tests with anti- Le^a serum were done on red cells from the same individuals. All proved to be secretors of A, B or H antigens and were $Le(a-)$. The only other groups so far reported who are 100% $Le(a-)$ are the Papuans of the Central Highlands of New Guinea (Semple et al., '56) and

American Indians (Chown and Lewis, '53). A high frequency was also reported in New Hebrideans (Simmons, Graydon, Semple and Malcolm, '54) and Australian aborigines (Simmons, Graydon and Semple, '54). It seems likely that this high frequency is characteristic of the New Guinea—Australian area and in this respect the Papuan pygmy is again like his neighbors.

Polunin and Sneath reported 17 non-secretors of A, B or H in a group of 58 Malayan Negritos which correspond to a frequency of .46 for *S*. They state that "the frequency of the gene for secretion of A-B-H substances is about the same as in other aboriginals in Malaya."

No data for the Lewis antigen or A-B-H secretion is available for the African Pygmies or the Negritos of the Philippine Islands. Büchi ('54) reports a high incidence (95%) of secretors of A, B or H substances in Negritos of the Andaman Islands, and points out that the secretor status of Negritos and Negroes who have a high incidence of non-secretors is "so clearly different that a relationship seems improbable."

Blood group P. Tests for the *P* factor were carried out on 91 samples of which 57 (63%) gave positive reactions. These results which indicate a gene frequency of .4 for *P* are presented with some reservation because the serum used was comparatively weak and some of the reactions tended to disappear fairly rapidly as the slide warmed up whilst readings were being made. Polunin and Sneath expressed similar doubts when reporting a value of .51 for *P* in Malayan Negritos. They also refer to the uncertain genetic basis of the serologically weaker forms of *P*.

Lehmann and Ikin found the frequency of *P* in 52 Onges to be .56 and Nijenhuis and van der Hoeven reported a lower frequency of *P* (.243) in Papuans from Biak.

However, the doubts expressed above seem to make it unlikely that further discussion of the *P* results will prove of value.

The Duffy blood group. Thirty of the blood samples selected at random from samples stored in glucose-citrate solution at

5°C for 6-9 months, were tested for the Duffy factor when a small quantity of anti-Fy^a serum became available to us. Of these, 27 were Fy(a+) and three were Fy(-) which corresponds to a gene frequency of .68 for Fy^a. Although the number tested was small this figure lies well within the range of frequencies so far reported for Asian-Australasian areas and contrasts with the low incidence of Fy^a found in Africa. Polunin and Sneath reported 28 Fy(a+) in 35 samples from Malayan Negritos and 28 Fy(a+) in 31 samples from Aboriginal Malays — results which are very similar to ours for the Papuan pygmies. No data relating to this factor are available for other Negrito groups or the African pygmies, but the difference in frequencies observed in Africa and Asia-Australasia suggest that the Duffy factor in African pygmies might be well worth investigating.

Ability to taste phenyl thiocarbamide. Some of the difficulties experienced in carrying out these tests with impregnated test papers have already been referred to, and although great care was taken in the performance of the tests, there remains some doubt as to the reliability of results obtained with primitive people communicating through an interpreter. This applies particularly to those classed as weak tasters. It is also unlikely that the group which could not be classified would contain tasters and non-tasters in the same proportion as in the whole sampling.

Of the 178 individuals tested for taste reactions 50 were classified as strong tasters, 12 as weak tasters, 64 as non-tasters and 52 could not be classified at all with confidence.

Abbie ('51) in discussing the Barrineans, an isolated pygmoid group living in the rain forests of the Atherton tableland, North Queensland referred to pygmies generally as follows — "At the present time there seems to be no particular reason to postulate any relationship between the different pygmy groups in different parts of the world (see Keith, 1948). Such evidence as there is supports rather the view that pygmies are modified representatives of the general local populace. They live in dense jungle or in elevated parts or

both or under conditions of relative isolation, and it is quite reasonable to assume that they have acquired their physical distinction by isolated inbreeding in an adverse environment."

A good deal of evidence bearing on the possibility of a relationship has accumulated since, and it is interesting to find that though conflicting in some respects most of it supports the view expressed by Abbie.

With few exceptions the blood group gene frequencies in each of the pygmy groups for which data are available fit very nicely into the pattern of frequencies of neighboring groups. It is also apparent that gross differences exist between the various geographically separated pygmy groups.

The only points of similarity that we observe in the African pygmies and Negritos are the absence of A_2 despite its presence in Negroes, and the high R^0 frequencies in the African pygmy and the Malayan Negrito. R^0 is of low frequency or absent in the other Asian pygmy groups. It seems strange that the African pygmy should lack A_2 when the A_2/A_1 ratio is high in Negroes. However, the absolute A_2 frequency is not high in Negroes, and it might be another instance of a gene being lost in a numerically small group due to random genetic drift.

Polunin and Sneath in referring to the high values of R_0 and absence of the sickle-cell trait in Malayan Negritos and Bushmen state "There is some evidence that the Negroids are late arrivals in Africa who brought with them the sickle-cell trait — and perhaps the "gene" *cde* also — from South-West Asia (Lehmann and Cutbush, '52). It is therefore possible that the Bushmen and Negritos are survivors of two racial types who were partly hybridized before the advent of the Negroids in Africa, the Bushmen being the source of the R^0 found in the latter two peoples. The position of the Melanesians (who have little R^0 or r and probably no sickle-cells) is still not clear; Birdsell (1949) suggests that they have evolved in Melanesia from a mixture of Negritos with several other

racial elements. The African pygmies who possess the sickle-cell trait also have a high incidence of R^0 (Hubinont and Snoeck, '49) but the Andaman Negritos lack both. The evidence for an African origin for the Asian Negritos is thus conflicting. It is possible, however, that genes may have been lost from small tribes . . . and this may have occurred in some of the Negrito populations. Alternatively, the Andamanese and the Melanesian Negritos may never have mixed with the Bushmen who might once have lived in parts of Asia."

Despite the finding of a high R^0 frequency in Malayan Negritos the present authors believe that the weight of blood grouping evidence makes it unlikely that the African and Asian pygmies are related. Previously we expressed similar views regarding the lack of relationship between the African and Oceanic Negroes (Graydon, '52).

Random genetic drift has been recognized as a major cause of changes in gene frequencies in small populations. This factor was emphasized by Polunin and Sneath who showed wide variations in gene frequencies between small isolates of the same Malayan racial groups. It is probable that in the past the numerical strength of these Oceanic Negrito tribes has been small as it is today and it is possible that variations as great as those reported could be accounted for by genetic drift alone. However, the similarity of the blood gene frequency arrays of each of the pygmy groups with those of its neighbors does not suggest that random forces have been the major ones responsible — rather does it suggest considerable local admixture as envisaged by Birdsell, or alternatively that these pygmoid groups are merely modified representatives of the local populace as Abbie suggests.

The blood group frequencies supplement the observations of Dr. Bijlmer, and support his opinion that the Papuan pygmies are, in fact, true Papuans. This survey has produced no evidence which would suggest that the Papuan pygmy is related to the African, and it would appear also that his relationship to other Asian pygmies is not close.

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SUMMARY

Blood samples from Papuan pygmies from the Wissellakes, Netherlands New Guinea, have been examined for the A-B-O, M-N-S, Rh, P, Lewis (Le^a) and Duffy (Fy^a) blood groups. In addition, tests were made to determine the ABH secretor status and ability to taste phenyl thiocarbamide.

The gene frequencies have been compared with those found in other pygmy groups and in neighboring populations. It is shown that the gene frequency arrays of the separate pygmy groups are very different from each other yet are similar to those of tribes inhabiting nearby areas. It is inferred that the Papuan pygmies are true Papuan, not apparently related to the African pygmies and that their relationship to other Asian pygmies is not close.

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ANTHROPOLOGICAL CONSIDERATIONS OF THE DIEGO (Di^a) ANTIGEN

POSSIBLE APPLICATION IN THE STUDIES OF MONGOLOID AND HYBRID POPULATIONS

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ONE FIGURE

Direct inheritance, freedom from the influence of environment and racial differences in distribution, are the genetic characters of the blood groups which make them especially useful in physical anthropology. The difference in distribution of the blood groups is only referred to in their variable positive incidence from one population to another, but it is never referred to an exclusive blood erythrocyte factor of the inhabitants of a country, or to an ethnical human division. However, the recent studies of a new blood group factor (Diego) indicate that it is a blood group antigen which is present in individuals of one ethnic human division while absent in those of another one.

The Diego blood factor was first described by Levine et al. ('54) in a review of the so-called "private" or "family" blood factors. The blood antigen was shown by an antibody developed in the serum of a Venezuelan woman through three consecutive pregnancies. The antibody (anti-Di^a) reacted by the anti-human globulin technic with the husband's red cells, but failed to react with 200 blood samples taken at random from white people.

In Venezuela, the investigations of the Diego antigen started in 1955, when a new pregnancy of the sensitized woman

offered one of the authors the opportunity to study the family and some groups of people representative of Venezuelan population.

Layrisse, Arends and Dominguez Sisco ('55a, '55b, '56a) found that the Diego antigen was inherited as a dominant mendelian character with no sex linkage, and the testing of 266 random individuals living in Caracas, surprisingly showed, that 6 unrelated people carried the factor. The most important finding, however, was that some members of the Diego family and the Diego positive cases of Caracas showed Mongoloid physical traits. The place of origin of the ancestors of these positive cases gave a clue to the possibility of Carib Indian admixture.

The Carib communities (Cariña) of "Cachama" and "Santa Clara de Aribi" situated in Anzoategui State, Venezuela, were the first Indian populations tested for the Diego factor. From 170 unrelated Carib Indians, 50 (29%) carried the Di^a antigen, thus confirming our suspicion. This important result encouraged Layrisse and Arends to extend the studies of this antigen to other Indian tribes, as well as to Negroes, Caucasoids, Asiatic Mongoloids and hybrid populations, in order to find out the antigen's real racial significance. Some months later, serologists from various parts of the world started to test the Diego factor in other populations, contributing a great deal to the knowledge of its distribution.

*Distribution of the Di^a antigen among the
American Indians*

Venezuelan Indians. Five Indian tribes have been tested in Venezuela: Carib, Arawak, Guahibo, Piaroa and Warrau. Of those, the Carib and Warrau have been studied in more detail.

In addition to the studies of the Carib communities previously mentioned (Anzoategui State), Nuñez Montiel and Nuñez Montiel ('57) have recently tested 125 unrelated Carib Indians from Rio Negro in the Western part of Venezuela.

They found an incidence of Diego positive very similar to that found by us, e.g., 25% Di^a positive in Caribs from Rio Negro and 29% in Caribs from Anzoategui State. If we consider these Carib subtribes to have been isolated from one another for hundreds of years, it can be surmised that the high frequency of this antigen is a genetic character of the Carib Indians and the antigen should be found in high frequency in other Carib subtribes, such as the Maquiritare in the Territorio Amazonas (Venezuela) and the Caribs from Guiana.

Layrisse, Arends and Wilbert ('58) carried out two expeditions to the Orinoco Delta to study two Warrau Indian Communities: Guayo and Winikina. On a first expedition they visited the Mission of "San Francisco de Guayo" where three Diego positive cases of a total sample of 81 were established. The second expedition was directed to the Winikina, a Warrau subgroup, which has been living in complete isolation until very recently. In this Indian population, not a single Diego positive case was found among 71 samples taken from individuals unrelated to each other.

The low incidence of the Di^a antigen among the Guayo-Warrau and the negative incidence among the Winikina-Warrau can not be explained by interbreeding with Caucaoids or Negroids, because the Warrau tested had a frequency of 100% of gene *O*, and negative frequency of the *cde* and *cDe* chromosomes of the *Rh* system. Thus, Layrisse et al. ('58) assumed that the Warrau Indians were not carrying the Di^a antigen originally, and that it was introduced to the Guayo-Warrau by admixture with Indians carrying the gene, such as Arawak and Carib, with whom the peripheral Warrau have been in contact since pre-historic times. Brett (1868) reports the existence of communities at the British Guiana where Warrau, Carib and Arawak Indians were living together.

The only tribe of Arawak descent tested for the Diego antigen is the Goajiro living in the North-west of Venezuela, for the study of which, Layrisse, Arends and Dominguez Sisco ('55a, '56a) chose the village of "Ziruma" situated only a

few kilometers from Maracaibo City. This village, founded 20 years ago, is formed mainly by Goajiro Indians and a small proportion of Caucasoids and Negroids.

Although only adult and unrelated Goajiro Indians were chosen for the blood group tests, it was found that these Indians have some admixture with either Caucasoids or Negroids or both. Thus, from 152 samples, 6 were group *A* (3.94%), two group *B* (1.31%) and one *Rh₀* (*D*) negative. Regarding the Diego antigen, only 8 blood samples were positive (5.26%).

If we consider the Goajiro as representative of Arawak Indian stock, it could be assumed that the Arawaks carry the Diego factor in low incidence. However, these data are to be confirmed by studying other Arawak tribes such as those living in the Orinoco Delta and the Venezuelan Amazon Territory.

Layrisse, Arends and Dominguez Sisco ('55b) had the opportunity of testing Guahibo and Piaroa Indians while carrying out an expedition to the Venezuelan Amazon Territory in 1955. Seventy-six blood samples were taken from unrelated Guahibo living in the surroundings of Puerto Ayacucho. The serology of blood groups showed an incidence of 99.5% of gene *O* and 100% of gene *D*, indicating almost complete absence of Caucasoid or Negroid admixture. The Diego factor was present in 14.5% of the Indians studied.

The Piaroa Indians live in small bands of 20 to 50 people, separated from each other by long distances. This peculiar habit makes it extremely difficult to obtain a large number of blood samples from unrelated people. Thus, Layrisse, Arends and Dominguez Sisco ('55b) could only take 24 blood samples from two settlements and from an agricultural colony, "Nuestra Señora de Coromoto." All blood samples were group *O* and *Rh₀* (*D*) positive. The *Di^a* antigen was present in 12.5%.

During the current year another expedition to the Amazon Territory of Venezuela will carry out further studies among different Piaroa and Guahibo Indian populations trying to

increase the number of blood samples of both tribes, in order to approach the true incidence of this factor.

Other South American Indians

Three groups of serologists studied other South American Indians. Junqueira et al. ('56) found 46% of Diego positives in Caingang Indians and 36% Diego positive in Carajá Indians. These tribes have shown the highest frequency of this factor. Allen (personal communication) in an expedition to Hacienda Vicos, Ancash, Perú, studied about 300 Quechua Indians who showed that 25% of them carry the factor. Meza Arrau (personal communication) found 4 Diego positive out of 100 samples of Araucano Indians.

North American Indians

The group of serologists from the "Rh Laboratory," Winnipeg, Canada, has made important contributions to the study of the Diego factor. In their first communication (Lewis et al., '56a) they demonstrated that the Chippewa Indians of Canada have a frequency of 11% of the factor. Some months later, in another communication ('56b) they reported the findings in two other Indian tribes: the Crees and the Eskimos. From 25 blood samples taken from the Crees, three samples were Diego positive, and not a single positive case was found in 156 Eskimos from the Eastern Canadian Arctic, which includes Hudson's Bay, Baffinland and Labrador. This negative incidence of Diego factor among the Eskimos was the first indication that not all Mongoloids carry the factor.

This year, Chown ('58) reported a negative incidence also in another 68 Eskimos, but he found three Diego positive cases out of 50 blood samples from Indians living in Eastern Alberta. However, he stated that the last group were not selected since it was not possible to rule out whether they were Eskimos.

Regarding other North American Indians, 66 Blackfeet Indians from Western Canada, were recently studied by Chown (personal communication) which revealed three Diego posi-

tive cases. In the United States, Gershowitz (personal communication) has found two positive cases out of 80 blood specimens from Apache Indians.

*Distribution of the Di^a antigen in
Asiatic populations*

Since it is generally admitted in anthropology that almost all American Indian tribes descend from the Mongoloids of the Old World, the study of the incidence of the Diego factor among the Asiatic people appears to be very important. Thus, a few months after the discovery of high incidence of Diego factor (Layrisse et al., '55a) among Carib Indians, Layrisse and Arends ('56b) and Arends and Layrisse ('56) determined the incidence of Diego among Chinese and Japanese. Out of 100 unrelated adult male Chinese from Canton, China, resident in Venezuela, 5 were shown to carry the antigen; and from 65 Japanese represented by 28 residents of Venezuela and 37 members of the crew of a Japanese fishing ship, 8 were Diego positive (12.3%). Almost at the same time, Lewis et al. ('56a) found 7.79% of Diego positives among Japanese living in Canada.

Little work, concerning the new blood factor, has been done in Asia. As far as we know, there is not yet a single serologist or anthropologist in China testing this antigen. In Japan, Furuhashi et al. ('57) have reported a frequency of 2.27% of positive cases; and Naohiko Veno (personal communication) has found 5 (6.7%) Diego positive out of 74 random samples of unrelated Japanese in Kumamoto, Japan.

Recently, Colbourne, Ikin, Mourant, Lehmann and Thein ('58) studying the hemoglobin E and the Diego factor in Burma and Sarawak, found a positive case out of 10 Burmese, and three positive cases out of 61 people from Land Dyak; but 85 blood samples from the Sea Dyak tribe were negative.

Negroid populations

In Venezuela there are no isolated populations of pure African Negroes. During the Colony and also thereafter, they

have mixed extensively with Indians and Caucasoids. Thus, the Diego positive cases found in two groups of Venezuelan Negroid populations were interpreted as Indian admixture (Layrisse et al., '55a, '56a, '56b, '57a). The first group studied was the little village of Curiepe, located in Miranda State, and the second group was represented by 119 unrelated samples taken from Negroes of the little villages of Farriar, Palmarejo and Aguas Negras in Yaracuy State.

Of the first group, 11 out of 150 people were found to carry the antigen, and in the second group, only 4 out of 119 people. Concerning the *ABO* system, the gene *O* expressed as *r* was 76.45% in people from Curiepe, and 77.23% in Yaracuy State. This high frequency of gene *r*, as compared with the frequency of West African Negroes, is indicative of an admixture with another race carrying a high incidence of group *O*, such as the Venezuelan Indians.

Other groups of American Negro populations have been studied afterwards with negative results: they were 35 Negroes living in Canada, examined by Lewis et al. ('56b), 120 Negroes from Brazil examined by Junqueira et al. ('57), and 27 Negroes living in the United States examined by Stern (personal communication).

Concerning the African Negroes, Layrisse and Arends ('57b) studied 107 blood samples from Negro tribes of the Gold Coast: Ga, Twi, Busanga, Fanti and Andagbe, with negative results for the Diego antigen. Negative findings were also found in 65 Negroes from the Ivory Coast studied by Gershowitz (personal communication).

All the data presented here indicate that the Negroes, at least those from West Africa, do not carry the Diego antigen, and that the positive incidence in the two Venezuelan Negro populations is probably due to Indian admixture.

Caucasoids

The frequency of the Diego factor has been examined in United States, Holland and Venezuela. Negative findings

were observed in 1000 Caucasoids studied by Levine et al. ('56) in New Jersey, and 200 Dutch tested by van Loghem (personal communication).

In Venezuela, with the recent European immigration, it is possible to study thousands of Europeans not mixed with natives. Thus, Layrisse and Arends ('57) could test 1400 unrelated adult Caucasoids from Spain, Italy, Poland, Russia and Hungary, of whom not a single individual carried the antigen.

The finding of a second sample of anti-Di^a in the serum of the mother of a Polish family (Levine et al., '56) is apparently contradictory to the negative findings in European Caucasoids including Poles. However, since the population of Poland is anthropologically considered to be a mixture of Caucasoids and a proportion of Mongoloids, the Diego positive Polish family may indicate admixture with Mongoloids carrying the factor, although this admixture is in a very low proportion since 200 random Polish samples were negative.

Oceanic populations

Simmons ('57) tested some Pacific populations with the anti-Diego serum. He did not only find negative results in 162 Australian aborigines, 23 Papuans and 74 natives of New Britain, but also in 80 blood samples from Polynesia.

Regarding other Oceanic populations, J. L. de Vries and L. E. Nijenhuis ('58) have found negative results in 84 Papuans from the Sentani-lake (S.W. of Hollandia, New Guinea); Nijenhuis and Soeparto Setjodihardjo obtained the same result with 91 blood samples from Semarang (Indonesia). As we mentioned before, Colbourne, Ikin, Mourant, Lehmann and Thein ('58) obtained three Diego positive cases among Land Dyaks, and negative results in Sea Dyaks.

In New Zealand, Staveley has started to test the Maoris for the Diego antigen; until now, he has not found any positive case in 85 Tuhoe and 7 Arawa (Lehman, North and Staveley, '58).

Since the Indonesians are a population predominantly Mongoloid, and the Polynesians show Mongoloid strains, it is surprising to find negative results of Diego antigen in these groups. These results probably indicate that the Mongoloid population which entered into the formation of Indonesians and Polynesians, did not carry the factor or, that it was in such a low frequency that no positive case could be found among the number of specimens tested.

Other populations

Nijenhuis (personal communication) has recently tested 100 blood samples of Arabians from Iran (Persia). They were all Diego negative. He has also tested American Indians from Surinam, finding 11 Diego positives out of 67 Lower Stream Indians (Coastal region) and one positive case out of 6 Upper Stream Indians (Trio and Dajana Indians).

DISCUSSION

To date, the Diego blood group antigen and hemoglobin E are the only genes which permit differentiation of the Mongoloids from other human ethnic divisions. However, the area of distribution of these genes is quite different.

As far as we know (fig. 1), the Diego antigen area extends from South America to North America and the North Eastern part of Asia including China and Japan. The frequency seems to decrease towards the South Eastern part of Asia, becoming negative in Oceanic populations situated below 0° latitude, even in populations with Mongoloid ancestry such as those from Indonesia and Polynesia. The incidence in the North, West and Center of Asia is still unknown.

According to the finding of this antigen among American Indians and Asiatic Mongoloids and the general admission that almost all American Indian tribes descend from the Asiatic Mongoloids, it could be postulated that there is, or there was, a population somewhere in Asia, which carries or carried the Diego antigen in a very high incidence. Anthropo-

logic studies of this population, if it could be found, should give a great deal of information about the relations between the American Indians and the Asiatic Mongoloids.

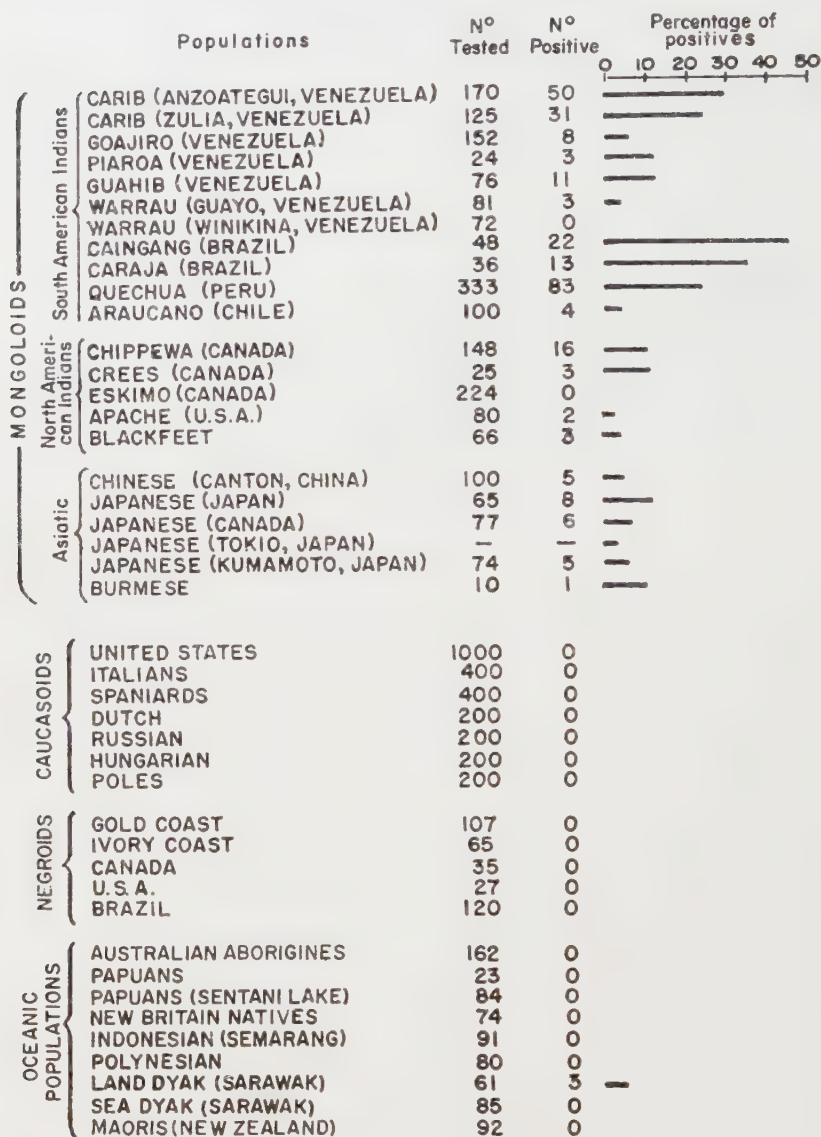


Fig. 1 Frequency of the Diego (Di*) antigen.

Within the extensive area of Diego positive genes, it has been found that in spite of their undoubtedly Mongoloid strain, two populations have been shown to be negative. We refer to the Canadian Eskimos and the Warrau of Orinoco Delta in Venezuela. The surprising feature of the Eskimo of the Eastern Canadian Arctic has not been explained by the authors who studied them (Lewis et al., '56; Chown et al., '58); however, Colbourne, Ikin, Mourant, Lehmann and Thein ('58) suggested that the negative incidence of Diego in Eskimos is an indication of early dispersal from some center of Mongoloid origin. Regarding the Warrau, it can only be said that they belong to the most primitive tribe of South America studied for this factor.

The area of hemoglobin E is practically limited to South East Asia (Colbourne et al., '58), the highest frequency (13-16%) being found in Burmese, Siamese and Malayan Malays. This incidence decreases to 2.6% in Indonesians, and to less than 1% in Bengalis, Gurkas, Sarawaks and Veddas of Ceylon. This hemoglobin has not yet been found in Chinese nor in American Indians, even in those who showed a high incidence of the Di^a antigen (Arends and Layrisse, '55).

The studies of the Diego factor carried out so far, give way to the conclusion that it is one of the few blood group antigens exclusive to an human ethnic division. Thus, its presence in most of the Asiatic and American Indian populations so far tested, and its absence in Caucasoids and probably in Negroids, makes the factor a useful tool in anthropology, especially for the study of Mongoloids and hybrid populations.

The variable frequency of this antigen among the Mongoloid populations, and the negative finding in some of them, is also of great importance because it should permit one to segregate the large Mongoloid stock into various groups according to the Diego factor frequency. This division may be of great help in the study of Mongoloid migrations when, in the future, many populations will be tested.

Assuming that the frequency of the Di^a antigen is negative or very low in Caucasoids and West African Negroes, the

rate of Indian admixture in three hybrid populations of Venezuela has been calculated. These populations are the result of interbreeding of Caucasoids (mainly Spaniards) West African Negroes and Carib Indians. They are: Curiepe, Ciudad Bolivar and Caracas. Among the Negroid population of Curiepe 23.3% of Carib admixture was found; in Ciudad Bolivar 22.3%, and only 6.3% in the population of Caracas. The rate of admixture found in Caracas must be considered only approximate, since part of the people consist of Mestizos coming from different sections of the country. The rate of gene Carib admixture was calculated according to Bernstein's formula ('31).

Occasionally, there is more than one Indian tribe which can be considered to be the basic element of a hybrid population, so that it is very difficult to determine which is the true one. This year, while studying the descendants of Guayqueri Indians, Layrisse, Wilbert and Arends ('58) demonstrated the usefulness of the determination of the incidence of the Diego antigen, in finding out whether they were a sub-tribe of Carib or Warrau Indians.

Since at the present time, there is not a pure Guayqueri Indian community, the village of Fajardo situated on the Margarita Island, Venezuela, was selected to test these Indians. This village was formed by Guayqueri Indians, Negroes from West Africa, and Caucasoids, mainly Spaniards. The 12% Diego positive reactions demonstrated without doubt that the Guayqueri who entered into the formation of Fajardo, were of Carib origin.

Since most of the South American Indian tribes show an incidence of ABO, Rh, MN, Duffy, etc., corresponding with each other, it is practically impossible to determine if a certain Indian tribe is pure or if it has been mixed with neighboring tribes, using only the blood group test. However, with the help of this new blood group antigen, it could be possible to determine the rate of admixture from one tribe to another. The study of the Warrau, as mentioned before, is a good example.

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SEROLOGY IN PHYSICAL ANTHROPOLOGY

TECHNICAL PROBLEMS AS REVEALED BY REPEATED BLOOD DETERMINATIONS IN TWINS¹

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Recent advances in serological genetics, which in themselves have implications for the anthropologist, demonstrate beyond question the need of a greater awareness in anthropological studies of certain problems in serological techniques. Our purpose here will be to examine some of these problems in the light of current knowledge and experience.

Variations in the strength of agglutinations have been recognized, described, and have constituted a major problem from the very beginning of the science of serology. With improvement in serological techniques, and the understanding of serological genetics, it has come to be recognized that variations in reaction strength for the different blood factors may frequently depend upon the genetic constitution of the donor. A few of the more important demonstrations of the genetic complexity of the blood group properties and their variations are: Malone and Dunsford ('51) for Rh; Sanger and Race ('51) for MNS; Race, Sanger, and Lehane ('53) for Duffy; Levine et al. ('55) for ABO; Ceppellini, Dunn and Turri ('55) for certain Rh combinations. These genetically determined deviations from simple or single gene expression that have now been observed, whether as a result of dosage effect or gene interaction, are all characterized by some quantitative effect upon the strength of reaction in serological tests. This has led Ceppellini, Dunn and Turri ('53) to state

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what only a few years earlier would have been taken as near heresy in many genetic as well as anthropological circles: "that for the blood groups as for other characters, the phenotype can not be regarded in any case as a direct reflection of the genotype."

The indisputable demonstration of the genetically determined differences in strength of agglutination in all of the major blood group systems place more, rather than less, importance upon the extra-genic factors which may also affect the strength of agglutination reaction. The extra-genic factors that may alter the strength of agglutination, and thereby affect the accuracy of the determinations, have been extensively described in the serological texts, where it is generally assumed that the occasional occurrence of these extra-genic influences will result in random error, the errors being first in one direction, and then in the other, depending upon the circumstances which prevail at a given time (Schiff and Boyd, '42, p. 219). However, even if genetic differences in reaction strength are ignored, consideration of a few of the different factors which may cause errors in blood typing will immediately indicate that an assumption of random error would be overly optimistic for many, if not most, population or anthropological studies.

Schiff and Boyd ('42, p. 24-38) list a number of factors influencing the strength of agglutination which would easily be encountered in population studies, characterizing particular population samples more than others, and thereby invariably leading to directional, rather than random, error. Whether the errors resulting from such causes can be treated as random, or directional, will depend importantly upon whether the data collected under different circumstances are to be combined or compared. In population studies, data are frequently obtained over a limited period of time under a specific set of circumstances unique to the time and population studied, for the purpose of comparison with other populations studied at different times under different conditions. The unfortunate application of the concept of random error

to all population studies, whatever the objective, has contributed without question to an insufficient appreciation of the importance of the problem of determination error, or respect for the complexity of the serological techniques.

The purpose of this paper is to present evidence of the magnitude or frequency of determination error, and the relative reliabilities of tests of the different blood group systems when carried out under nearly ideal conditions. A method of alleviating the most probable sources of error encountered in the present data will also be suggested, which would be practical in the application of serology to anthropological studies.

MATERIAL AND METHODS

The blood group data presented here were obtained in the course of carrying out the diagnosis of twin zygoty (Osborne, '56). Since an intrapair difference in a single blood factor is considered sufficient evidence for the diagnosis of dizygoty, the accuracy of determinations is critical for twin diagnosis. Therefore, it seemed advisable to at least obtain control determinations. This was done by dividing each blood specimen, and having different professional laboratories independently carry out the blood group determinations. With the early discovery that discrepancies were occurring, repeated determinations were done for every twin subject studied. In each instance where a discrepancy occurred, a new specimen was obtained and at least a third determination performed. At no time did a laboratory know the results of its own previous determinations, or those of another laboratory, (code numbers were used for labeling specimens).

Employing sterile technique, 20 cm³ specimens were drawn by vena puncture from each subject. The specimens were divided into sterile 10 cm³ Wassermann tubes, and the clots immediately refrigerated. All determinations were made as soon as possible, usually within 24 to 48 hours, and transportation of specimens was only for short distances. All determinations were done in the routine manner by the most skilled

professional blood technicians in three different leading blood laboratories. The subjects were between the ages of 18 and 55 years, and in good general health.

RESULTS

The number of separate blood determinations and the frequencies of the discrepancies for each blood factor are listed in table 1. The differences in the number of separate blood determinations for the various blood factors result in greater

TABLE 1
Blood group determinations

BLOOD FACTOR	NUMBER OF SEPARATE DETERMINATIONS	PERCENTAGE OF DISCREPANCIES ¹		
		Determinations	Individuals	Twin pairs
ABO	371	.54	1.56	1.64
Rh				
D	363	0	0	0
C	363	0	0	0
E	363	.28	.79	1.64
c	308	.65	1.87	1.92
MN	313	2.86	8.11	9.19
Duffy	326	3.99	8.93	12.50
Kell	338	6.21	12.07	12.07
Le ^a	76	6.58	16.67	20.00
S	286	10.49	19.30	22.81
P	105	21.90	40.91	50.00

¹ The percentages of discrepancies include the within laboratory, as well as between laboratory, discrepancies.

part from differences in their frequencies. The n of 371 for the ABO series is the total number of times independent determinations were performed, as every specimen could be tested for this series, while the n of 363 for D, C, E, in the Rh series results from the fact that there were 8 instances of Rh negative blood tested. Because in 55 determinations the blood specimens were homozygous for C, only 308 c determinations were made. The unavailability of testing sera, or a serum absorbed for the appropriate factors also contributed to a smaller n in some cases.

The proportion of discrepancies in table 1 represent the within laboratory, as well as between laboratory, discrepancies. A difference in the typing of any one specimen of cells from an individual is counted as a discrepancy. The differences in the percent of discrepancies for determinations, individuals, and twin pairs in a particular blood factor result mainly from the fact that one discrepancy would typically represent one out of three determinations, and one individual from one twin pair. The departures from a perfect progression of percentages which would thus be expected represent the occurrence of cases in which errors occurred in both members of a twin pair, as well as instances in which more than three determinations were obtained for a given individual.

The order of reliability or repeatability for the different blood groups is very close to what might be anticipated. No errors occurred with D and C of the Rh series; and there were only two errors in the ABO, these involved misclassification of AB individuals as Type A. The repeatability of the ABO and Rh determinations were found to be good, MN and Duffy fair, Kell and Lewis poor, S and P were extremely unreliable.

Examination of the present data reveal that the occurrence of a determination error is the result of something other than personal error, and that such errors can only be detected by actual test. No instance of a questionable determination was encountered in compiling table 1, and in the technician's judgment, every recording represented a definite reaction. While there did appear to be some correlation between grouping error and the time lapse in the drawing of the specimen and the laboratory test, the distance the specimen was transported, as well as the warm summer months, no specimen was observably deteriorated. Consequently, there was no hint of discrepancies in the factors ascribed, or suspicion that such might be occurring, until the results of the independent determinations were compared. While obviously the first essential in the accurate recording of blood determinations is the technician's experience and ability in performing the test and interpreting different agglutination phenomena, the second essential is the

strength of agglutination reaction characterizing a particular factor, and subsequently the strength of the particular testing sera. An example of the latter was observed with the P factor, in which no discrepancies occurred with the use of one particularly strong anti-P serum. The other and probably also typical P sera, however, resulted in discrepancies in 21.9% of all P determinations performed. As the determinations and their discrepancies reported here were done by different laboratories over a period in excess of one year, different testing sera were employed, even within the same laboratory, and the discrepancy frequencies can therefore be taken as representative for the blood group, and not just of a particular testing sera.

DISCUSSION

The blood determinations presented here were repeated for the purpose of obtaining the most reliable diagnosis of twin zygosity possible, and for the purpose of evaluating the importance of determination error in zygosity diagnosis, when tests were done in the routine manner customarily employed in genetic and anthropological problems. Since this study was not designed to solve serological problems, too extensive an interpretation of these data should not be attempted from this standpoint. More important, however, is the fact that for any given blood group, the discrepancy frequencies listed in table 1 will pertain only under the conditions which characterize the present study; conditions far more favorable than could reasonably be obtained in the majority of anthropological or population studies. Consequently, the actual frequency of discrepancies listed in table 1 should perhaps be considered near minimal for anthropological studies when the customary procedure of obtaining single determinations from refrigerated blood clots is employed. On the other hand, the uniform procedure followed in this study with the repetition of every blood group determination, on every specimen, and for every individual, whether or not an error was indicated,

should make it possible to take at face value the relative reliabilities of the different blood groups as listed in table 1.

The frequency of determination errors revealed in the present study would in all probability be greatly exceeded under the conditions encountered in many anthropological or population studies. Even on the basis of the grouping error demonstrated here, the significance of this problem for both the anthropologist and geneticist should be self evident. To the professional serologist these data will not be a surprise, for it is the magnitude of this problem which has necessitated development of the elaborate procedures employed in blood bank work. Certainly for whatever the purpose of the blood determinations, the most experienced blood technicians, and the best available testing sera, are to be found in the well equipped professional laboratory. However, if the services of the professional laboratory are to be efficiently utilized, it is necessary to deliver the blood specimens to the laboratory in the best possible condition: a condition which can not be grossly observed, but must be determined by actual test. Methods are presently available which make it possible to preserve and ship blood to the professional laboratory for reliable blood determinations, checking, storage and future use. It may be that in the future it would be well to consider these as principal serological field techniques in population studies.

A recommended procedure

Following establishment of the importance of the blood discrepency problem for twin diagnosis, the following procedure was evolved, with the advice and assistance of Dr. Cahan of the Knickerbocker Foundation Inc., for properly preparing and delivering specimens to the blood laboratory. All bloods were drawn as previously specified, and placed in 10 cm³ sterile tubes, to which was added one part of A-C-D solution to 4 parts of blood, plus the addition of two drops of a combination of Streptomycin and Terramycin. The addition of Penicillin to the cells should be avoided, for it has recently been found that antibodies directed against this anti-

biotic may be formed (Ley et al., '58). The A-C-D Solution is a commercial preparation, composed of citric acid, sodium citrate, and dextrose, used for storing whole blood. The acid decreases hemolysis, the citrate functions as an anti-coagulant, and the dextrose maintains cell vitality. The antibiotic is added to prevent bacteriogenic activity; the most convenient preparation is an aqueous suspension. A similar procedure for preserving and shipping blood, using instead one part of Alsevers Solution to one part of blood, has been published by Dr. Cahan ('55). When the purpose of the blood determinations is for diagnosing twin zygosity, double determinations are obtained. Following this procedure over 250 individuals have been typed for all of the factors listed in table 1, and from these, selected specimens have been flown to England for rechecking, while others have been retyped many months later after freezing in glycerol. In none of these have any discrepancies in typing been detected. Similar success using a like procedure has been reported in the literature (Mollison et al., '52; Brown and Hardin, '53; Chaplin et al., '54; Donahue et al., '56).

SUMMARY

Repeated blood determinations on twins for the purpose of obtaining accurate zygosity diagnosis resulted in the discovery of serious discrepancies in blood typing. The reliability of typing ranged from good reliability for the Rh and ABO systems, to extremely poor reliability for S and P. The potential magnitude of this problem in interpreting comparative blood data for different population samples is discussed, and a practical means for reducing the risk of determination errors is proposed.

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THE DENSITY OF SELECTED BONES OF THE HUMAN SKELETON ¹

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ONE FIGURE

The degree of mineralization of bones is estimated for both experimental and clinical purposes by various roentgenological techniques. It is common practice for the clinician to evaluate the degree of atrophy or hypertrophy by subjective inspection of roentgenographs. Signs of decreased mineralization are described as a generally increased translucence (radiolucence), irregular areas of reduced density in the spongy bone, thinning of the cortex with the appearance of lamellae, and a general ground glass-like appearance (Lachmann and Whelan, '36; Sante, '55). However, absence of these signs does not preclude the presence of reduced mineralization as the reduction must be appreciable before such changes are evident in standard roentgenographs. Lachman and Whelan ('36) examined serial roentgenographs of bones after the removal of known amounts of mineral by artificial decalcification. They found that, "Only under very favorable circumstances can decalcification under 20 per cent be diagnosed. In most bones the calcium loss, in order to be visible, must be in the vicinity of from 20 to 40 per cent." And, they added that, "The amount of decalcification necessary for diagnosis varies considerably in different bones and in different parts of the same bone." More recently, Sante ('55) estimated that evidence of demineralization of less than 30% was not apparent in roentgenographs. There is some evidence

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to show that all bones of the skeleton, and all parts of the same bone are not equally and simultaneously affected by these changes. Earliest and predominately affected (by systemic causes) are believed to be those bones largely composed of spongiosa such as the hip bones and vertebrae (Albright and Reifenstein, '48). It has been stated, further, that much of the cancellous portion of a bone may be removed entirely without evidence of change in the roentgenograph (Snure and Maner, '37; Young and Funk, '53). Therefore, it may be said that subjective roentgenologic study of mineralization can be misleading unless the changes are severe.

A device for objective determination of mineral density from averaged densitometric readings along a linear path on standard roentgenographs has been developed at Pennsylvania State College (Mack, Brown and Trapp, '49). If an estimate of bone volume is included, the result is an expression of bone density. It is hoped that this method will provide a practical means for quantitative assessment of the mineral content of bones in living subjects.

Bohatirchuk ('57) has studied macroradiographs of a large series of living individuals and both macroradiographs and historadiographs of a large series of human skeletons. His findings suggest subjective differences between the radiographic signs of the changes resulting from normal aging and osteoarthritis.

While an evaluation of decreased mineralization by the clinician is usually compatible with other findings in a given clinical circumstance, a study of the relationship between bone changes and aging has not been carried out on a statistical basis. Rather, it is generally believed that most of the changes of old age are due to atrophy and in terms of the skeleton atrophy is osteoporosis; that bone density decreases in the female after the menopause (post-menopausal osteoporosis is the commonest of all forms); that density decreases with age after 70 years (senile osteoporosis); and, that in many cases of osteoporosis various predisposing causes (disease, malnutrition, post-menopausal state and senility) are

inseparably superimposed. Also, it is assumed that bones of the Negro are more sturdy than those of the White, and that bones of the male are more sturdy than those of the female.

The present study is concerned with bone density as understood by the classical definition of density, or weight divided by volume. The volume in this case is that which is enclosed by the surface of the bone and includes both the substance of the bone and the marrow cavities contained within its surface. Thus, density here denotes the amount of bone present per unit volume and not the specific density of bone substance. Of necessity, such studies can be made only on post mortem remains. Whole bones are considered, and comparison is made between two parts of each skeleton, one largely cancellous bone and the other largely compact bone.

The purpose of this paper is to determine the density and the quantitative changes which may occur with aging in the lumbar vertebrae and femurs of series of White and Negro skeletons of both sexes.

MATERIAL AND METHOD

Eighty dry, fat-free skeletons selected for equal distribution for each sex of American Whites and Negroes constitute the material. The age range in years of the 20 skeletons in each of the four groups is as follows:

White male, 42-94; female, 25-91;
Negro male, 27-84; female, 33-100.

For each individual, the cause of death as reported to the Missouri State Anatomical Board neither was associated with primary skeletal disease nor implied secondary pathological involvement of the skeletal system. Furthermore, the bones after skeletonization showed no gross changes other than those usually associated with the process of aging. The skeletons were macerated, brought to the dry, fat-free state, and weighed according to the methods outlined by Trotter and Peterson ('55). One slight difference was introduced, however. Occasionally, it was necessary to keep the bones immersed in acetone for longer than twenty-four hours, in

order to have all the fat extracted. In such instances the acetone was replaced with a fresh supply every twenty-four hours. Experience has indicated that residual fat in the bone may be detected by inspection. The lumbar vertebrae and femurs of each skeleton were studied.

The determination of the volume of each series of lumbar vertebrae and of each femur was carried out in a 4000 cm³ graduated cylinder (standard make), using millet seed as the medium displaced. The latter was chosen because its size is small enough to provide suitable packing and large enough not to enter the bone through foramina normally present on the surface. Hence, the volume measured was limited by the external surface of the bone(s).

The seed entered the graduate by flowing from a large, smoothed and varnished wooden hopper. The upper part of the hopper is square, measuring 26 cm on a side and 15 cm in depth; the lower part slopes for a distance of 24 cm terminating in an outlet 2 cm square. A metal slide with a similar opening is so placed that when the slide is pulled the two openings coincide exactly. The hopper is secured with its outlet 69 cm above the table.

The lumbar vertebrae were placed in the graduate simulating the anatomical position and the femur with its distal end resting on the bottom. With the slide of the hopper in the closed position approximately 1½ times the amount of seed required to fill the graduate was poured into the hopper. The graduate was placed on the table and centered under the outlet of the hopper, after which the slide was moved to the open position permitting the millet seed to flow into the graduate. When the bone(s) was covered with seed the slide was closed, and the graduate was carefully moved forward on the table. The column was leveled by gently scattering the seed with the end of a thin wooden rule. The level was read to the nearest graduation (50 cm³) and estimated to the nearest 5 cm.³ Next, the hopper was emptied, its outlet closed, the contents of the graduate poured into it and the bone removed. The seed was run into the same graduate

and a reading taken again. The volume of the bone(s) is considered to be the difference between these two readings.

Care was taken to avoid packing of the seed other than that which occurred as the result of the flow of the seed itself, not only because of the experience of Stewart ('34) in cranial capacity studies but, also, because of tests which involved shaking the graduate and/or compressing the column of seed. All volume determinations were made by the same individual (G.E.B.).

The statistical procedures were selected and carried out by Barbara Bartels Hixon, to whom grateful acknowledgment is made.

TESTS OF THE METHOD

Ten series of lumbar vertebrae and 20 femurs were chosen at random and the measurements of seed volume repeated in order to determine the reproducibility of the measurements.

Methods for determining bone volume using water as the medium have been suggested. Such a method is not directly applicable in this study, since the volume so determined is that of the bone substance without regard for its distribution. However, for purposes of comparing the precision of the millet seed determination (method 1) with that of other volume methods, the volumes of the twenty femurs chosen at random were measured by three methods using water.

The first water method involved the same principle as the millet seed method, that of simple displacement. The empty 4000 cm³ graduate was filled with water to a level sufficient to cover the bone when it would be immersed, and a reading taken. The femur was lowered into the water with its distal end down; in some cases the bone floated momentarily. The top of the graduate was covered, and after twelve hours another reading was taken. The difference between these two readings is considered to be the bone volume (method 2).

The use of Archimedes' principle provides a more refined method for determining volume. The difference between the weights in grams of a femur in air and in water is equal to the volume of the bone substance in cubic centimeters (method

3). It is necessary to recognize the possibility of trapped air in a bone when it is immersed in water, even though 12 hours is allowed for air bubbles to escape. To reduce this error the bone, immersed in water, was kept for one hour in a chamber in which the pressure was reduced by 26 inches of mercury, after which the volume was again determined by Archimedes' principle (method 4). The amount of trapped air should be substantially reduced in the latter instance but not necessarily eliminated altogether (Liebermann, '57). However, it may be expected that method 4 provides the most accurate measure of the volume of the bone substance present.

TABLE 1
Reliability of different methods for determining the volume of bones

METHOD	BONES	AVERAGE VOLUME		AVERAGE ABSOLUTE DIFFERENCE	PERCENT AVERAGE DIFFERENCE ¹
		1st	2nd		
		cm ³	cm ³	cm ³	
1	Vertebrae	315.5	314.5	4.0	1.3
1	Femurs	514.0	499.0	18.0	3.5
2	Femurs	211.2	194.3	31.6	15.0
3	Femurs	207.5	188.9	21.1	10.2
4	Femurs	155.7	157.8	4.5	2.9

¹ Average absolute difference/average of first volume.

Each measurement was repeated. Table 1 shows for 10 series of lumbar vertebrae and 20 femurs the results of the first method and for the femurs the results of the other three methods: the averages of the first and of the second measurements (cm³), and the average of the absolute differences between the two measurements expressed in cubic centimeters and in per cent of the average of the first measurements. This difference in per cent may be referred to as the per cent error of the method and, as an evaluation of precision, may be used to compare one method with another. The increase in precision of method 3 over method 2 may be ascribed in part to the accuracy with which each measurement could be read; the volume determined by method 2 was read from 50 cm³ graduations estimated to the nearest 5 cm³, while the volume by

method 3 was read from 0.2 gm graduations estimated to the nearest 0.1 gm. It may be noted that there was a marked increase in precision when steps were taken to evacuate trapped air from the internal bone structure by method 4. The precision of the millet seed determination by method 1 compares favorably with that of the most precise water method, even though the measurements with millet seed were estimated, as in method 2, from 50 cm³ graduations to the nearest 5 cm.³ It is believed, therefore, that the millet seed method provides a measure of the volume enclosed by the external surface of the bone(s) which is reproducible within a small range of error.

RESULTS AND DISCUSSION

The volume and weight were measured of each series of 5 lumbar vertebrae as a group; the measurements of each pair of femurs were averaged in each instance, since the variation between right and left measurements was negligible.

The mean age, weight, volume and density of the vertebrae and the femurs for each of the four groups and their standard deviations are presented in table 2.

The mean ages of the two White groups are older than of the Negro groups, and of the two female groups than of the male groups; the range of the means among the four groups is 7.6 years. The weights, volumes and densities of the vertebrae are less than of the femurs, and in each instance less in Whites than in Negroes and in females than in males.

Differences among group means. In each of the 4 groups the mean density of the vertebrae was shown by the analysis of variance to be significantly less than that of the femurs ($P < .001$).

An analysis of variance of the differences among the densities of each series of bones was carried out as follows:

SOURCE OF VARIATION	DEGREES OF FREEDOM	MEAN SQUARE	VARIANCE RATIO (F)	P
Vertebrae				
Among 4 group means	3	.0441	3.9	< .05
[Male vs. Female]	[1]	[.0144]	1.3	
[Negro vs. White]	[1]	[.1179]	10.4	< .01
[Interaction]	[1]	[.0000]	< 1	
Within groups (error)	76	.0113	1	
Femurs				
Among 4 group means	3	.0368	2.8	< .05
[Male vs. Female]	[1]	[.0297]	2.3	
[Negro vs. White]	[1]	[.0794]	6.1	< .05
[Interaction]	[1]	[.0014]	< 1	
Within groups (error)	76	.0130	1	

For the vertebrae there is a significant difference among the mean densities of the 4 groups ($P < .05$). The three degrees of freedom for this source of variation were subdivided in order to determine how much of the variation could be accounted for by sex, how much by race, and how much by interaction of the two. Of these, only the difference due to race is significant ($P < .01$). For the femurs the variation among the mean densities of the 4 groups is also significant ($P < .05$), and again, the only one of the three subdivided sources of variation accountable for the significant difference is that of race ($P < .05$).

Even though the mean density in each male group is consistently higher for each series of bones than in the corresponding female group the present data do not indicate a significant difference.

Effect of age. When the densities of the vertebrae and of the femurs are plotted against age it is found that the densities decrease with age in each of the 4 groups (fig. 1). In each series the calculated slopes are significantly different from zero except for the vertebrae of the Negro male group. The results are as follows:

GROUP	VERTEBRAE		FEMURS	
	Slope	P	Slope	P
White male	— .0043	< .05	— .0049	< .05
Negro male	— .0019	> .05	— .0029	< .05
White female	— .0025	< .05	— .0035	< .05
Negro female	— .0033	< .05	— .0039	< .01

TABLE 2
Means and standard deviations (S.D.) of age (years), weight (gm), volume (cm³) and density (weight/volume) of vertebrae and femurs according to race and sex

GROUP	AGE		BONES	WEIGHT		VOLUME		DENSITY	
	Mean	S.D.		Mean	S.D.	Mean	S.D.	Mean	S.D.
White male	64.0	12.8	Vertebrae	110.4	20.4	276.5	49.0	.408	.098
			Femurs	310.4	54.9	499.8	63.1	.628	.114
Negro male	59.6	13.9	Vertebrae	135.4	40.2	277.0	60.7	.483	.097
			Femurs	356.0	59.8	511.2	72.6	.700	.087
White female	67.2	17.1	Vertebrae	79.8	22.9	208.8	36.3	.380	.080
			Femurs	200.0	48.7	339.6	66.6	.598	.121
Negro female	60.3	19.8	Vertebrae	101.9	24.6	229.0	42.1	.458	.141
			Femurs	235.6	44.2	368.0	59.4	.652	.129

A test of parallelism (Bliss, '52, p. 490) of the regression lines for the densities of the vertebrae of each of the 4 groups indicates that the slopes do not differ significantly from the

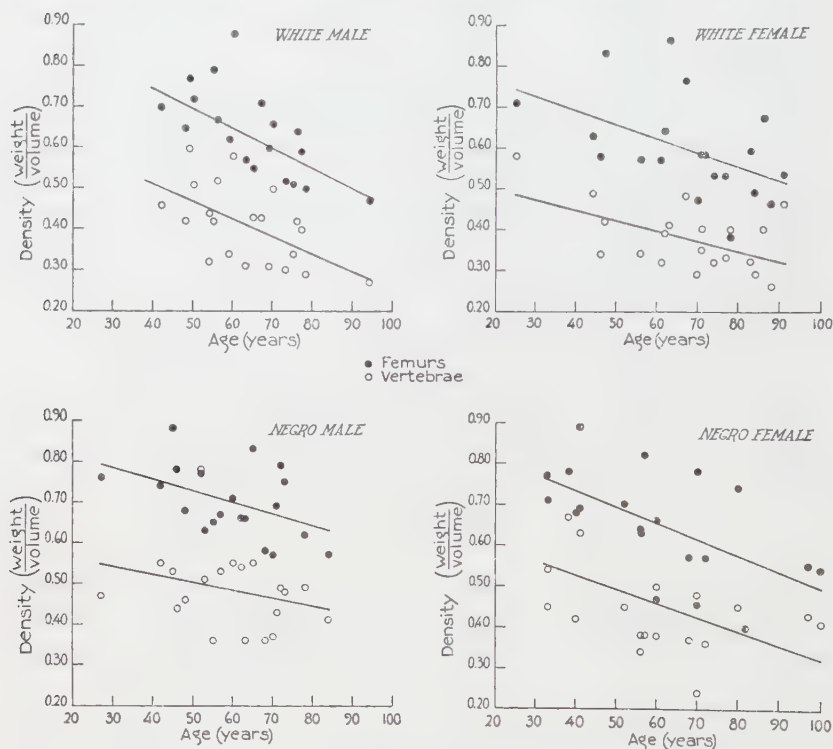


Fig. 1 Scattergrams and regression lines of densities of lumbar vertebrae and femurs according to age.

best fitting combined slope of the 4 groups.³ The combined slope is significantly different from zero ($P < .001$) and the divergence among the four slopes is less than the experimental (combined) error. The same test applied to the densities of

³ The combined slope is obtained by adding the sum of products, $\sum(x - \bar{x})(y - \bar{y})$, for each group and dividing by the sum of the sum of squares, $\sum(x - \bar{x})^2$, of the dependent variable for each group.

the femurs gives similar results. The tests of parallelism are as follows:

SOURCE OF VARIATION	DEGREES OF FREEDOM	MEAN SQUARE	F	P
Vertebrae for 4 groups				
Combined slope	1	.1744	18.8	< .001
Divergence in slopes	3	.0039	< 1	
Experimental error	72	.0093	1	
Femurs for 4 groups				
Combined slope	1	.2769	28.3	< .001
Divergence in slopes	3	.0021	< 1	
Experimental error	72	.0098	1	

A similar test of parallelism was made in each of the 4 groups to determine whether the slopes of vertebrae and femur densities on age differed from each other. No significant difference between the slopes for the two series of bones is found in any group. In each of the White groups the combined slope for vertebrae and femur densities differs from zero significantly at the .001 level. In the Negro male the combined slope differs from zero significantly at only the .05 level, whereas in the Negro female group the slope differs from zero at the .01 level.

Thus, it is seen that the vertebrae (except in the Negro male group) and femurs decrease in density with age, but it should be noted that the rate of decrease has not been shown to differ between the two series of bones within a group or for either series of bones according to race and sex.

Another aspect of the problem of the effect of age on density of bone is suggested by the clinical evidence that postmenopausal and senile osteoporosis may have different times of onset. Might it be possible that a curvilinear relationship (quadratic or cubic) would be a better fit for the trend of density with age than a straight line? To test this possibility the densities of the femurs of the Negro female series which has the widest age range (33-100) were grouped by decades (25-34, 35-44, etc.) and analyzed in 7 age periods. The linear

regression with age is less significant ($P < .05$) than when individual measurements are used showing that there is a loss of precision by grouping and that the scatter of the group means around the straight line is not significant. If more cases were available for each year, or for each decade, it would be possible to test whether a curvilinear relationship might be a better description than a linear relationship of the trend of density with age.

Differences among group means with correction for differences in age. Inasmuch as the mean ages of the White groups are older than of the Negro groups it is of interest to determine whether the difference in mean densities of both vertebrae and femurs accounted for by race may be attributed to the difference in ages.

A sum of squares for differences among mean vertebrae densities adjusted for age in the four groups was calculated by the analysis of covariance (Snedecor, '56, p. 395) with three degrees of freedom. The mean square for vertebrae densities (.0259) divided by the mean square for the appropriate experimental error (.0091), gives a variance ratio ($F = 2.8$) which is significant at the .05 level. A similar analysis for femur means adjusted for age gives a mean square of .0187 which, when divided by the experimental error for the femur (.0095), yields a variance ratio ($F = 2.0$) which is not significant.

The correction for age shows that the difference among densities of vertebrae in the two races is still significant at the .05 level although the variance ratio is smaller. For the femur densities, however, the apparent difference among groups ($P < .05$) disappears when a correction for age is made.

A subdivision of the variation among the group means adjusted for age by use of factorial coefficients in the analysis of covariance (Snedecor, '56, p. 409) shows the amount of variation which can be accounted for by differences in sex, differences in race, and the interaction of the two. For the vertebrae densities the only one of these sources of varia-

tion which is significant is that between the races ($P < .01$) as in the earlier analysis of variance when correction for age differences was not made. Although the femur densities are not shown to differ significantly in the analysis of covariance, the same subdivision of the variation among means into differences in sex, in race, and the interaction of the two shows that the difference due to race merely approached significance with P slightly greater than .05, whereas in the earlier analysis P was less than .05.

Thus, by the analysis of covariance *in which a correction for differences in age is made*, it is shown that the mean density of the lumbar vertebrae of Negroes is significantly higher than of Whites ($P < .01$), but that the mean density of the femurs of Negroes exceeds that of Whites with the difference merely approaching significance.

Finally, it should be recalled that this study is based on bones from only 80 individuals and that comparisons are made between groups with only 20 in each group. The similarity of the slopes of decrease in density with age of the vertebrae and of the femurs among the 4 groups and, also, between the two series of bones within each group suggests that the density of bones, whether largely compact or spongy, White or Negro, or male or female, is affected by age. It is possible that the differences in the densities due to race might be more distinct, or perhaps eradicated, and that differences between the sexes might become apparent when larger series of bones are studied.

SUMMARY AND CONCLUSIONS

The densities ($\frac{\text{weight}}{\text{volume}}$) of the lumbar vertebrae and femurs from 80 adult skeletons were determined. The skeletons were derived equally from American Whites and Negroes of both sexes, each group with a wide age range. Weight was taken of the bones in a dry, fat-free state; volume was measured by displacement of millet seed.

It was found that:

1. The mean density of the vertebrae is significantly less than that of the femurs in each of the four groups.

2. Although the mean densities of both vertebrae and femurs are less in Whites than in Negroes and less in females than in males only the difference between races is statistically significant.

3. There is a significant and parallel decrease in the densities of vertebrae and femurs with age in each group except for the Negro male group in which the slope for vertebrae is not significant.

4. The significance of the difference between races in the mean densities is reduced when a correction for differences in ages between the groups is made, and in the case of the femurs the difference is no longer significant.

Thus, on the basis of this study it is concluded that femurs are significantly more dense than lumbar vertebrae, that both are more dense in American Negroes than in American Whites but not more dense in males than females, that the density of both series of bones decreases significantly with age at approximately the same rate regardless of race or sex, and that after correction for age differences the difference between races is significant only for vertebrae densities and not for femur densities.

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NATURAL HEAD POSITION, A BASIC CONSIDERATION IN THE INTERPRETATION OF CEPHALOMETRIC RADIOGRAPHS

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EIGHT FIGURES

As early as the 1860's, craniologists realized that for cephalometric studies skulls had to be oriented in a manner approximating the natural head position in the living. Broca (1862) defined this position as follows: "when a man is standing and when his visual axis is horizontal, he [his head] is in the natural position." In order to determine natural head balance a horizontal or vertical reference line outside the cranium was used, but preference was given generally to the horizontal. It was recognized, however, that a true horizontal line cannot pass through the same two anatomical landmarks in all individuals.

Schmidt (1876) summarized the problem at hand by stating that "the horizontal positioning of the head is a physiologic concept, which we must find by observation of the living; when it is first determined how the horizontal plane traverses the living head in its normal position, then the next task is to apply this concept into craniology, that is to say which anatomical plane within the skull corresponds closest to the physiologic horizontal."

The Frankfort Horizontal (1884) is probably the best known and most acceptable approximation of the physiologic horizontal, yielding maximal differences in facial configuration between racial groups and supposedly having smallest variability within each group (Lüthy, '12). The Frankfort Hori-

zontal is a slight modification of the line suggested originally by Professor Merkel and used by him and by Von Ihering (1872). Merkel and Von Ihering used the midpoint of the *porus acousticus externus* as the dorsal termination of their line. At the Craniometrical Conferences in Munich and Berlin, Porion was considered to be a more suitable landmark, and the line from Porion to Orbitale was labelled as the German Horizontal. It became known as the Frankfort Horizontal after being adopted also at the Craniometrical Conference in Frankfurt am Main (1884).

When the technique of cephalometric radiography was introduced in the 1930's, orthodontists became interested in craniology. Many methods were developed to study the configuration of the face utilizing the Frankfort Horizontal as well as various reference lines in the cranial base (Krogman, '51). The Frankfort Horizontal originally intended for orienting skulls was now used to orient the living head in the cephalostat.

When the various methods of cephalometric analysis are applied to the study of an individual, the findings may differ markedly depending upon the choice of reference line, as shown by Krogman and Sassouni ('57) in their exhaustive survey of roentgenographic cephalometry. Actually their syllabus brings out the fact that interpretations of the same cephalogram may differ considerably according to the use of the Frankfort Horizontal or the line Nasion-Sella Turcica.

In the 17 year old female selected for study by Krogman and Sassouni, the Frankfort Horizontal line coincides with the "physiologic" or true horizontal. Hence the analyses based on the Frankfort Horizontal correctly describe this patient as having a "maxillary protrusion and normal mandible." Because the cranial base is deflected downward in its dorsal part, the analyses using Nasion-Sella Turcica as a reference line arrive at an opposite and incorrect conclusion, namely "normal maxilla and retrusive mandible." The Frankfort Horizontal, in contrast to the cranial base, can be used satisfactorily for studying the cephalogram in this par-

ticular instance. The situation is reversed in some individuals, and it is even possible that neither line is suitable for meaningful analysis of the facial configuration.

Björk's ('50) extensive studies of facial prognathism also illustrate the unreliability of intracranial reference lines. He selected two individuals to represent "maximum and minimum facial prognathism in adult male Bantus" relative to the line Nasion-Sella Turcica, but without reference to natural head position. Actually these two individuals have almost identical profiles and illustrate greatest variations in the inclination of the cranial base rather than differences in prognathism.

It is inevitable that prognathous individuals with a low cranial base will be grouped in the orthognathous category and orthognathous individuals with a high cranial base in the prognathous category, unless natural head position is taken into consideration.

The advantage of registering natural head position by means of a vertical line is illustrated by comparing cephalograms of two females with the closest similarity in their profiles, selected from a group of 61 senior students of the Forsyth School for Dental Hygienists. The marked differences in the slopes of both the Frankfort Horizontal and Nasion-Sella Turcica lines of these two individuals are shown in figure 1. Conventional cephalometric analyses utilizing these intracranial reference lines would yield markedly different findings for the configuration of the two faces.

PURPOSE OF THE STUDY

The primary purpose of this study was to test the hypothesis that the natural head position of man is relatively constant. Confirmation of this assumption introduces the possibility of utilizing an extracranial line of reference, namely the true vertical, for cephalometric studies. Subsequently the reliability of intracranial reference lines can be determined with respect to the vertical.

The principle of an extracranial line of reference is of basic value in the general study of the biologic variations of the cranial configuration in man. More particularly it permits an accurate assessment of facial development and of such characteristics as prognathism.

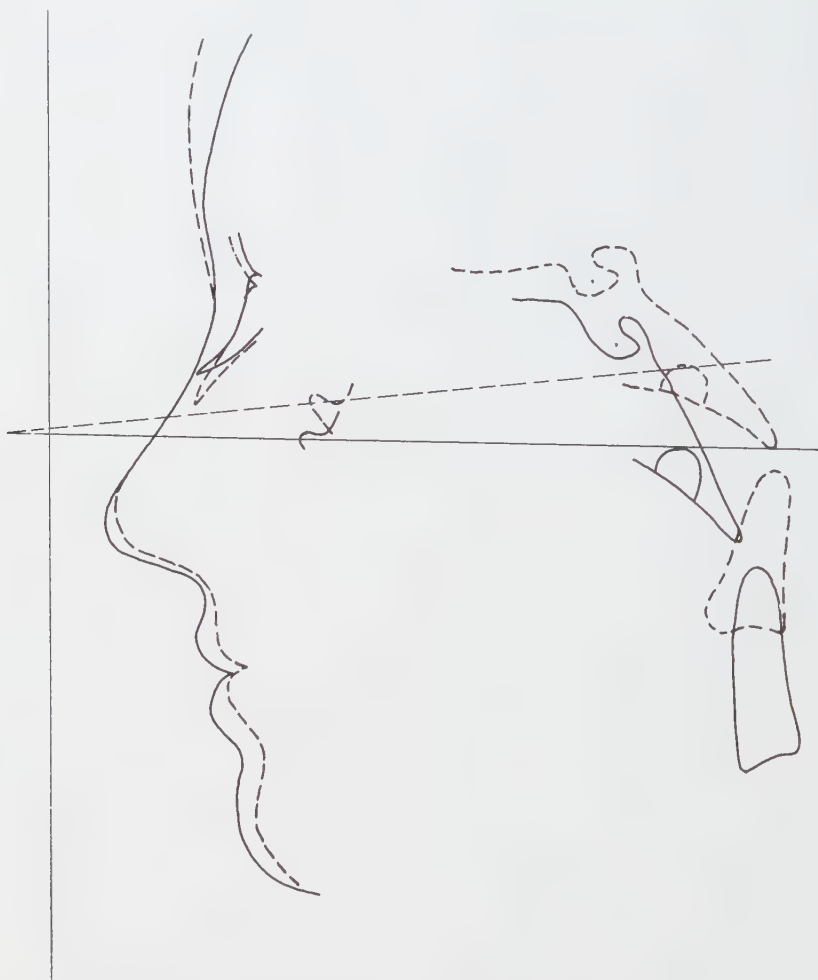


Fig. 1 Marked differences in the inclination of the cranial base and Frankfort Horizontal in two females with close similarity in facial profile. The cephalometric radiographs were taken with the head in natural position. The vertical is shown for reference purposes.

1. Natural head position

MATERIALS AND METHOD

Two groups of 18 to 20 year old females, students of the Forsyth School for Dental Hygienists, were radiographed in their natural head position. The first group, consisting of 66 freshmen students, was used in a pilot study in which the natural head position was not changed. Two radiographs were made of each subject with a time lapse of one week.

Since differences in head position might be explained in part by an occasional tenseness of the subject resulting in "unnatural" tilting of the head, it was decided to observe the head position of the second group of students prior to exposure and to correct this position, if necessary. Utilizing this precautionary measure, 61 members of the senior class were radiographed twice, again with a time lapse of one week.

The following modifications of the Broadbent cephalostat ('31) were necessary to permit radiography of the head without fixation and to record a true vertical on each film (fig. 2).

A brass bow with a stainless steel ligature wire, tightly stretched between its ends, was attached to the base plate of the cassette holder and the wire was aligned in the vertical by means of a spirit level. Since the wire was placed directly in front of the cassette, its image was recorded as the true vertical reference line on each radiograph.

To allow the head to assume its natural position, the ear plug for the left ear was removed and the arm supporting the rod for the right ear plug was turned away.

The distance between the film and the midline of the cephalostat was set at 100 mm. In order to obtain a constant distance between the midsagittal plane of the head and the film in each instance, the orientation of the midsagittal plane of the head had to correspond to the midline of the cephalostat. Two vertical bars were attached to the cephalostat, one in the place of the rod used for alignment of the frontal x-ray unit, and the other replacing the arm originally intended to support the head at the bridge of the nose. The line of sight be-

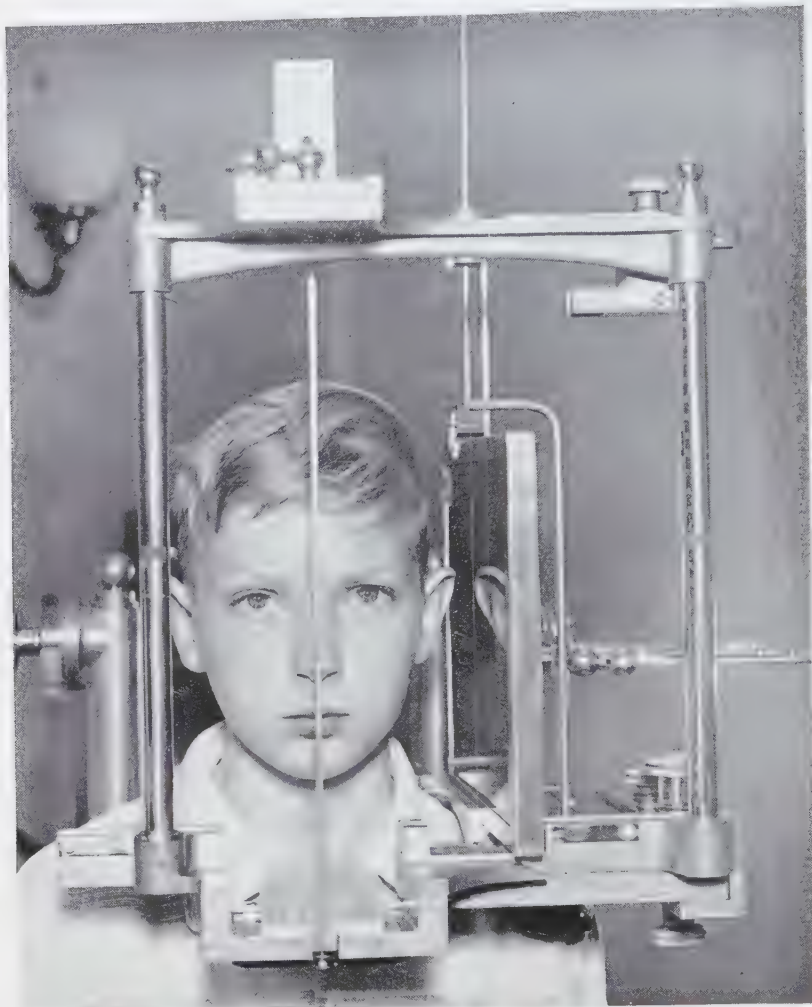


Fig. 2 Modification of the Broadbent cephalostat for radiography of the head in natural position. The subject is looking into a mirror.

Note that 1. a stainless steel wire is placed close to the cassette for registration of the vertical on the film. 2. the midsagittal plane of the head is aligned by means of two vertical bars, only one of which is shown, to maintain a constant distance (100 mm) from this plane to the film space. 3. the height of the subject's stool is adjusted so that the interpupillary line closely approximates the bottom of the tape mark on the left post of the cephalostat.

tween these two bars constituted the midline of the cephalostat and guided the orientation of the head in the midsagittal plane. It was, therefore, possible to keep the distance from the midsagittal plane to the film constant (100 mm) for each individual.

For the recording of natural head position, the subjects were instructed to sit comfortably and relaxed on a stool. They were asked to look into the image of their eyes in a round mirror located at the same level as the pupils of their eyes (Von Baer, 1861). The mirror had a diameter of 100 mm and was attached to the wall 170 cm in front of the original transmeatal axis of the cephalostat, in a plane parallel to this axis. The height from the center of the mirror to the floor was indicated by a tape mark on the front posts of the cephalostat. Once the subjects were seated, the stool was raised to bring the interpupillary line to the level of the tape mark (fig. 2).

These modifications of the Broadbent cephalostat do not contravene the principles of cephalometric radiography. In spite of the absence of head support, the quality of the radiographs was satisfactory.

On the radiographs Nasion and the midpoint of the outline of Sella Turcica were located. For greatest possible accuracy these two landmarks were marked with a needle on the first radiograph, and a tracing of the area was superimposed on the second radiograph of each individual to obtain identical location of these points. The line from Nasion to the midpoint of Sella Turcica was then drawn and extended, if necessary, to intersect the image of the vertical line (V).

The variability of head position at successive observations was determined by statistical analysis of the differences in the angle SNV, according to the formula:

$$\text{S.D.}_{\text{head position}} = \sqrt{\frac{\text{sum of differences}^2}{2n}}$$

FINDINGS

The standard deviation of head position in the 66 freshmen students was 2.05 degrees. In the 61 senior students the

standard deviation of head position was 1.54 degrees. This finding differed at the 5 per cent level of significance from that obtained in the pilot study according to the f test of variance.

This improvement in reproducing natural head position may be due to the fact that an unnatural tilting of the head was corrected, when it occurred, in the second sample studied.

TABLE 1

The means (M), their standard errors (S.E._M), and the standard deviations (S.D.) of angles, in degrees, between various intracranial reference lines and the vertical in 61 North American females, observed twice in natural head position and the correlation coefficients ($r \pm S.E._r$) of these angular measurements

	NASION-SELLA TURCICA AND THE VERTICAL			FRANKFORT HORIZONTAL AND THE VERTICAL		
	M	S.E. _M	S.D.	M	S.E. _M	S.D.
First examination (1)	85.28	0.50	3.92	92.21	0.51	4.02
Second examination (2)	84.74	0.47	3.67	91.68	0.47	3.68
$r_{1.2} \pm S.E._{r_{1.2}}$	+0.85	± 0.04		+0.85	± 0.04	

	HIS AND THE VERTICAL			BASION-OPISTHION AND THE VERTICAL		
	M	S.E. _M	S.D.	M	S.E. _M	S.D.
First examination (1)	93.30	0.45	3.55	84.84	0.86	6.69
Second examination (2)	92.75	0.46	3.57	84.47	0.82	6.37
$r_{1.2} \pm S.E._{r_{1.2}}$	+0.82	± 0.04		+0.95	± 0.01	

The accuracy of reproducing natural head position was determined also by correlating the angles between various intracranial lines and the vertical at the two observations of each subject, utilizing Pearson's product moment formula (table 1).

The relatively high degree of association between the angles SNV ($r = +0.85$) and the small standard deviation of differences between the angles SNV in the two series of observations are indicative of the remarkable constancy of head position in these North American females.

DISCUSSION

Unknowingly at the time, we had duplicated Schmidt's (1876) approach to the study of head balance. Schmidt stated that the natural position of the head with the eyes focused at the horizon was determined by muscular control. It also occurred to him that there might be disagreement among different observers regarding the correctness of the head position assumed by the individual. Schmidt studied his subjects first in the "self position" and subsequently in the "corrected head position." Ten repeated observations of 9 individuals made by Schmidt and of 11 individuals studied by him and by 5 other observers showed that head position could be reproduced with less variation when corrections were made in the self position, if necessary. In his investigations Schmidt used a light wooden frame to which a protractor and plumb line were attached (fig. 3). He concluded that Von Ihering's horizontal line had a mean angle with the true horizontal of 5.5 to 5.75 degrees, opening ventrally. The constancy of head position was reported to be greatest in "muscular and intelligent people."

Downs ('52) also aware of possible deviations of the Frankfort Horizontal from the true horizontal in individuals, photographed 100 orthodontic patients while they were standing and looking into their own eyes in a mirror. The Frankfort Horizontal differed on the average 0.9 degrees from the true horizontal, the lines diverging ventrally. In 1956 Downs reported this difference to be 1.3 degrees, with a standard deviation of 5.0 degrees. Bjerin ('57) studied natural head position, again by means of Von Baer's (1861) method. Three observations of 35 Swedish adults showed that the maximal variations in head balance were slightly, but not significantly, greater in the sitting position than in the standing position.

It should be pointed out that the central x-ray does not always pass through the same point of the cranium (e.g. Porion) when individuals are radiographed in their natural head position. This is of no consequence, since peripheral areas of the cranium are enlarged radiographically to the

same degree as are areas close to the central ray. In other words, the cranium is uniformly enlarged without distortion on a lateral head radiograph. Proof of this statement has been obtained by Hamernik ('57) and by Kean ('58) who demonstrated absence of peripheral distortion in a radiograph of a centimeter grid, using a Margolis cephalostat.

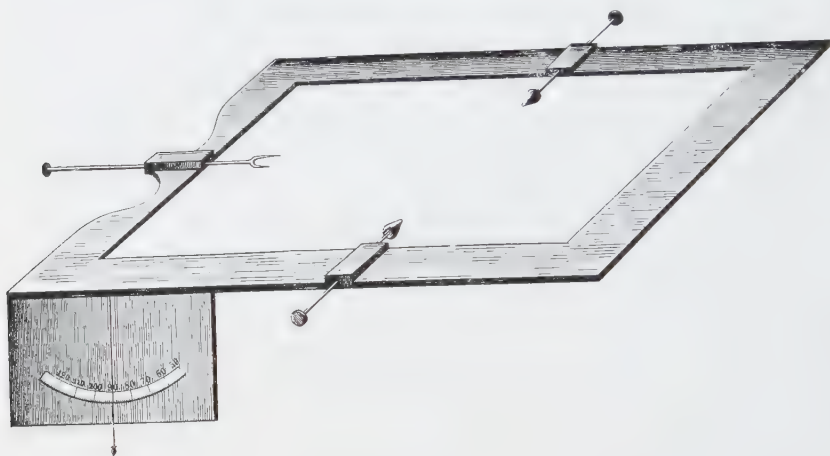


Fig. 3 Frame with protractor and plumb line used by E. Schmidt (1876) to determine the relation of the Frankfort Horizontal to the vertical and subsequently to the true horizontal.

The method presented for obtaining cephalometric radiographs with the head unsupported, the eyes looking in a mirror, and the patient seated or standing at ease, may be of advantage also in the registration of the so-called rest position of the mandible.

The self alignment of patients has the advantage of giving a truer picture of facial asymmetry. When patients are lined up in the cephalostat according to conventional techniques, it is assumed that the transmeatal axis is perpendicular to the midsagittal plane. If this is not the case, the immobilization of the head with ear plugs introduces a degree of asymmetry proportional to the deviation of the transmeatal axis from the midsagittal plane.

A vertical reference line can be recorded also on profile photographs thereby extending the usefulness of photography to the study of prognathism and to clinical orthodontics.

II. Intracranial reference lines

MATERIAL AND METHOD

Once the relative constancy of head position had been established, it was possible to use the true vertical in determining the reliability of reference lines in the cranium for cephalometric radiography, the relation of these lines to each other, and the ranges of their individual variation.

For this part of the study, the two radiographs taken in natural head position of the 61 senior students of the Forsyth School for Dental Hygienists were used. In addition to the line Nasion-Sella Turcica, the Frankfort Horizontal, the His line, and a line connecting Basion and Opisthion were drawn on the first radiographs of these individuals (fig. 4).

The landmarks were ascertained according to the definitions given by Krogman and Sassouni ('57), and their location was systematically checked by the two authors. However, the highest point of the mandibular condyle was substituted for Porion since the latter landmark could not be located with sufficient accuracy. When the shadows of the left and right condylar or orbital points did not coincide, the midpoint was marked.

The Frankfort, His, and Basion-Opisthion lines were drawn on one radiograph only. The angulations of these lines to the vertical were measured and recorded. The differences between the angles Nasion-Sella Turcica and the vertical on the two radiographs of each individual were already obtained. The differences for the angulation of all other lines on the two radiographs had to be exactly the same and, therefore, the angles between the various reference lines and the vertical on the second radiograph of each individual could be computed by adding or subtracting the difference obtained for the angle SNV.

FINDINGS

The mean angles, standard errors of the means, and the standard deviations for the various reference lines relative to the vertical are given in table 1.

The variation (S.D. ranges from 3.55 to 6.69 degrees) of these intracranial lines is greater than the variation (S.D. = 1.54 degrees) in registration of head position ($P < 0.01$). Therefore, the method outlined for obtaining cephalometric radiographs in natural head position and the use of the true

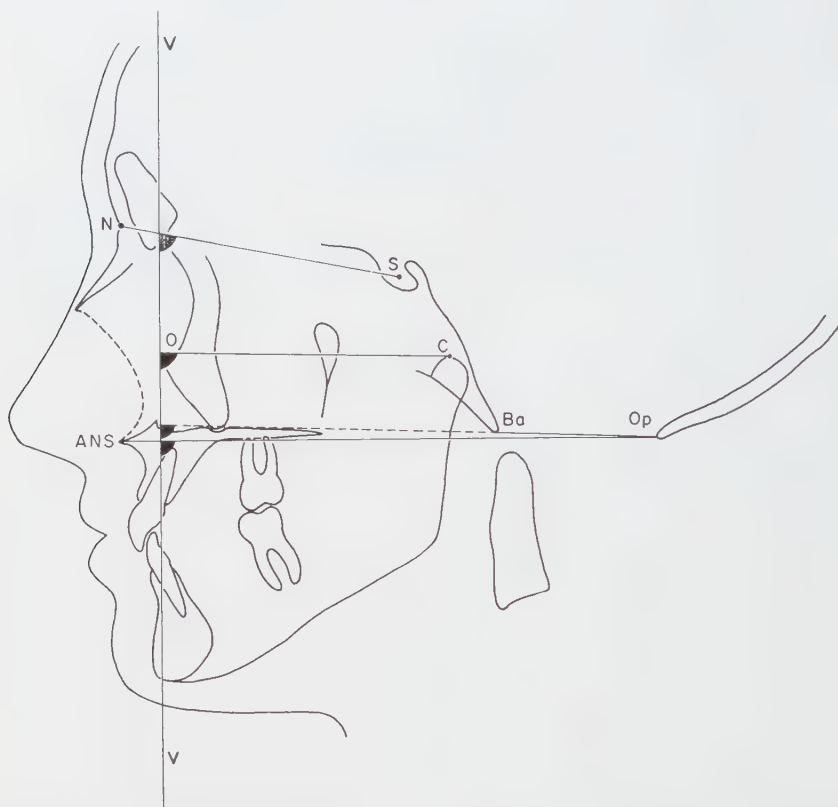


Fig. 4 Intracranial reference lines. Nasion-Sella Turcica (N-S); Frankfort Horizontal, Orbitale to highest point on the mandibular Condyle (O-C); His, Anterior Nasal Spine or Acanthion to Opisthion (ANS-Op); Basion-Opisthion (Ba-Op). The registration of natural head position with reference to the vertical (V) is shown also.

vertical line for reference purpose is more reliable than the routine use of such lines as the Frankfort Horizontal or Nasion-Sella Turcica line.

Differences between the means of the two series for any line of reference are not statistically significant, in fact, the largest difference between means is no greater than 0.55 degrees. Moreover, the standard deviations of the angles of the same reference line with the vertical at subsequent observations do not differ significantly.

With the exception of the line Basion-Opisthion, the difference between the standard deviations of the various intracranial reference lines are not statistically significant according to the data obtained at either the first or the second observation. The angle between the vertical and the line Basion-Opisthion has the largest standard deviation, differing significantly from the others ($P < 0.01$), as a consequence of the small distance between the two landmarks and the marked effect of their positional variation on its inclination with the vertical. The correlation coefficient of the angles between the line Basion-Opisthion and the vertical at two observations is high ($r = +0.95$) because the correlation coefficient is proportional to the large standard deviation of this angle.

The greatest distance between terminal landmarks is found for the His line explaining the slightly, but not significantly, smaller standard deviation of the angle between this line and the vertical, relative to those of other lines studied, except Basion-Opisthion.

Table 1 also contains information about the average inclination of reference lines to the vertical. The Frankfort Horizontal and the His line are almost perpendicular to the vertical. The Nasion-Sella Turcica line intersects the vertical at approximately 85 degrees. The average facial angle in orthognathous Swedish males is likewise about 85 degrees (Björk, '47). This figure was used as a basis of reference in a previous study of cephalometric radiographs by means of the mesh diagram (Moorrees, '53).

Coefficients of correlation expressing the degree of association between the inclination of various intracranial reference lines were computed from the angles between these lines and the vertical (table 2). The inclinations of the lines Nasion-Sella Turcica to Frankfort Horizontal, Nasion-Sella Turcica to His, and Frankfort Horizontal to His are correlated to a moderately high degree (r ranges from $+0.73$ to $+0.80$). The correlation coefficients measuring the relationship between the line Basion-Opisthion and Nasion-Sella Turcica or Frankfort Horizontal are low ($r = +0.45$ and $+0.56$, respectively) because the individual variation of the inclination of Basion-Opisthion exceeds that of the others. The correlation coefficient of the His and Basion-Opisthion lines is rather high ($r = +0.79$), probably because these two lines have Opisthion as a common terminal landmark.

TABLE 2

The relation between various intracranial reference lines measured by the correlation coefficients ($r \pm S.E._r$) of the angles between these lines and the vertical in 61 North American females

	NS-FH	NS-His	NS-BaOp	FH-His	FH-BaOp	His-BaOp
r	$+0.78$	$+0.73$	$+0.45$	$+0.80$	$+0.56$	$+0.79$
$S.E._r$	0.05	0.06	0.10	0.05	0.09	0.05

With the exceptions mentioned above, the various correlation coefficients are of sufficient magnitude to conclude that, in general, deflection of one intracranial reference line in a given individual is accompanied by the deflection of others in the same direction. Yet, while the Frankfort Horizontal may be satisfactory for analytical purpose in an individual, another line, for instance, Nasion-Sella Turcica, may not be acceptable.

III. Interpretation of cephalometric radiographs

The importance of natural head position for the interpretation of cephalograms can be shown by the mesh diagram analysis. This method has the advantage of illustrating the findings in graphic form.

The mesh diagram is essentially a coordinate method of analysis. The principle of coordinates probably dates back to antiquity and was already in common use by painters of the sixteenth century, notably Albert Dürer. Moreover, a system of two rectangular coordinates was employed by Lucae (1864) to study the facial configuration.

Various systems of coordinates can be used to construct a mesh diagram, as was shown by Sir D'Arcy W. Thompson ('17) in comparing the form of structures or parts thereof. The simplest of these is a net of rectilinear equidistant coordinates, and this method was applied by De Coster ('39) to the analysis of cephalometric radiographs.

According to Moorrees ('53), and Moorrees and Yen ('55) the line Nasion-Sella Turcica is suitable for the orientation of the mesh diagram on the face. When the cranial base has an upward or downward deflection, it may be necessary, however, to discard this variable intracranial reference line and instead use the vertical, as follows:

1. Draw a line through Nasion, parallel to the vertical (line 1).
2. Draw two lines perpendicular to line 1, one through Nasion and one tangent to the lowest point on the border of the mandible (lines 2 and 3, respectively).
3. Transfer the distance Nasion-Sella Turcica on line 2 and divide it in three parts.
4. The fourth line of the basic rectangle is parallel to the vertical (line 1), but perpendicular to lines 2 and 3. It is drawn through a point on line 2 at a distance from Nasion which is $\frac{4}{3}$ of the length of the distance Nasion-Sella Turcica.
5. The basic rectangle is divided vertically and horizontally in four parts, resulting in a mesh diagram of 16 rectangles which inscribes the face.

To illustrate deviations from the average location of anatomical landmarks in their respective mesh rectangles, the horizontal or vertical mesh lines are distorted. The mean findings for a group of 50 North American females, who were

also students at the Forsyth School for Dental Hygienists (Moorrees, '53), can be used as a standard of reference irrespective of whether the mesh is oriented on the vertical or on the line Nasion-Sella Turcica (fig. 5). The average angle of the cranial base to the vertical (SNV) closely approximates 85 degrees, and this figure was used in the con-

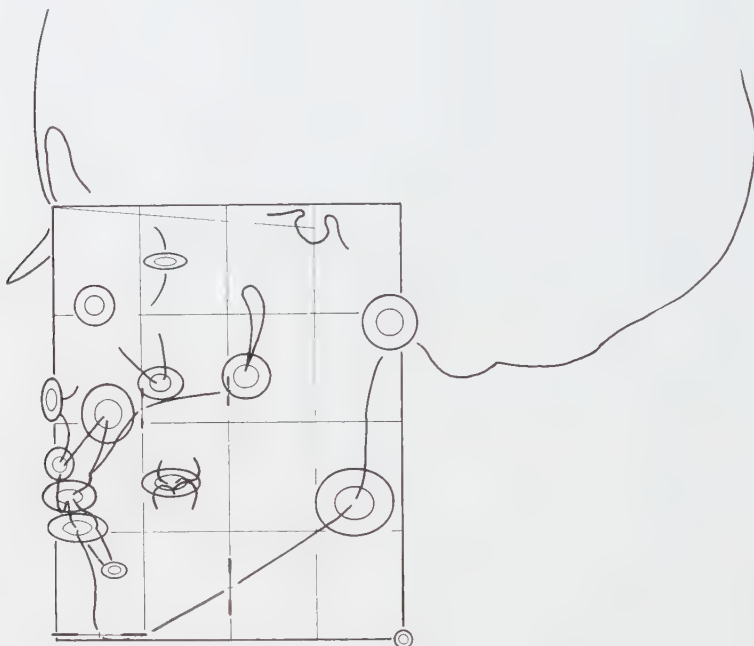


Fig. 5 The average facial pattern of 50 North American females determined by means of a mesh diagram (Moorrees, '53). The concentric ovals show the ranges of individual variation for the location of landmarks in their respective rectangles at the one and two standard deviation limits.

struction of the original mesh based on the line Nasion-Sella Turcica. Thus, the orientation of the mesh diagram on the face is fundamentally the same in both methods, except when the inclination of the cranial base to the vertical differs from 85 degrees. In such instances it is necessary to orient the mesh on the true vertical for meaningful interpretation of the cephalogram. The vertical line has been recorded on the clinical photographs in the following illustrations.

Figures 6 and 7 show the mesh diagrams and photographs of the two senior students with close similarity of their profile outlines. The inclination of the cranial base to the vertical differs markedly in these two individuals (fig. 1) and, therefore, their bony profiles are dissimilar according to the distortions of the mesh based on the line Nasion-Sella Turcica (figs. 6A and 7A). The mesh oriented on the vertical (figs. 6C and 7C), on the other hand, confirms the likeness of the two faces.

The tracings of these individuals indicate some of the possible variations in the relationship between two intracranial lines of reference. In one, the Frankfort Horizontal is perpendicular to the vertical (fig. 6C). In the other, the slope of the Frankfort Horizontal corresponds to the high inclination of the cranial base (fig. 7C). Differences in natural head position of these girls at two observations with a one-week interval were 0.5 and 1.5 degrees, respectively.

A marked discrepancy between findings of cephalometric analysis and clinical examination is shown in figure 8. Due to a pronounced downward inclination of the cranial base, the protusion of the maxillary incisors is masked completely and the slight mandibular retrusion exaggerated (fig. 8A) when the line Nasion-Sella Turcica is used in the construction of the mesh diagram. Figure 8C shows the true nature of the facial configuration as well as the caudad position of the Sella Turcica. Three radiographs of this boy were made in the natural head position, two on the same morning, and the third 4 months earlier. No difference in head position on the three records could be found, the difference in the angles SNV was zero.

In summary, the authors consider that the procedure outlined not only simplifies the technique of cephalometric radiography but that it also facilitates meaningful interpretation of the cephalogram for clinical and research purposes. The technique can be used advantageously in clinical photography and permits cephalometric radiography without a cephalostat. Furthermore, it may provide a new approach to the study of facial asymmetry.

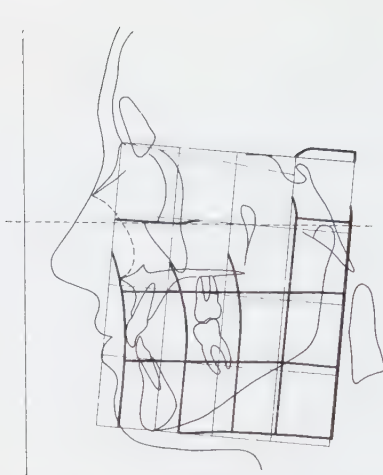


Figure 6 A

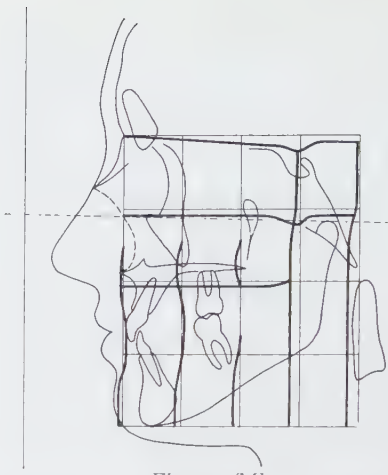


Figure 6 C



Figure 6 B

Fig. 6 Mesh analyses and profile photograph of a Forsyth student. A, mesh diagram constructed on the line Nasion-Sella Turcica; B, photograph of the subject; C, mesh diagram oriented on the vertical line. The vertical line is shown in figures 6A, B, C.

Since the cranial base has a downward inclination in this instance, the distortions of the mesh diagram based on the line Nasion-Sella Turcica (fig. 6A) give an erroneous impression of the facial configuration.

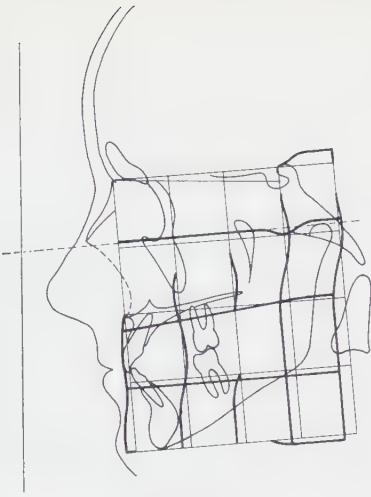


Figure 7 A

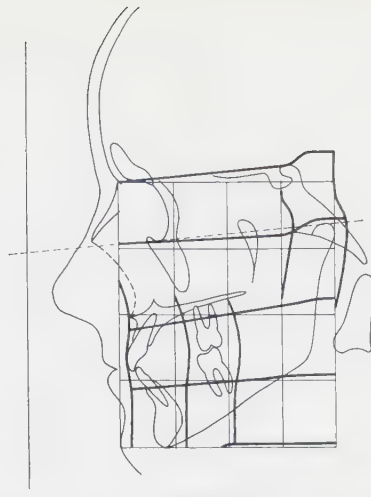


Figure 7 C



Figure 7 B

Fig. 7 Mesh analyses and profile photograph of a Forsyth student with close similarity in facial profile to the student shown in figure 6. Upward inclination of the cranial base and Frankfort Horizontal line, as shown by the distortions of the mesh oriented on the vertical (fig. 7C), making it impossible to use either for cephalometric analysis.

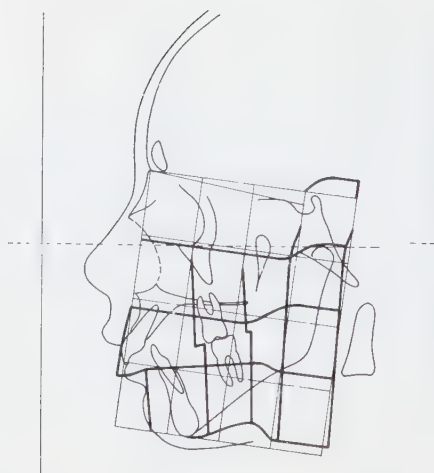


Figure 8 A

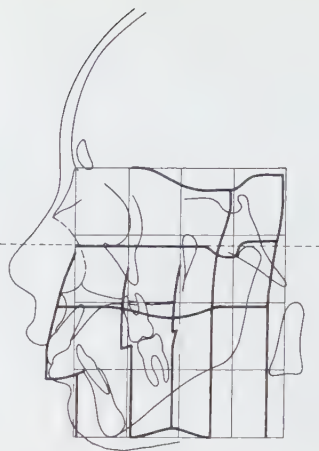


Figure 8 C



Figure 8 B

Fig. 8 Mesh analyses and profile photograph of an 11 year old boy. Complete masking of a severe protrusion of the maxillary incisors occurs when the mesh is oriented on the markedly deflected cranial base (fig. 8A). The downward inclination of the cranial base, as well as the protrusion of the maxillary incisors and "normal" mandible, are shown clearly by the distortions of the mesh based on the vertical line (fig. 8C). These findings corroborate the clinical evaluation (fig. 8B). It should be pointed out that the Frankfort Horizontal line is perpendicular to the vertical and may be used for cephalometric analysis in this instance.

CONCLUSIONS

According to principles of craniometry established approximately one hundred years ago, the registration of natural head position is essential for cephalometric studies. The line of reference used in the analysis of cephalometric radiographs must reflect the orientation of the head in space.

In 61 North American females, the position of the head was found to be remarkably constant at two observations with an interval of one week. The subjects were radiographed while seated at ease, with the head unsupported and the eyes looking into their own image in a mirror.

The true vertical, or a horizontal perpendicular to it, is preferable to reference lines within the cranium, since the biologic variation of the intracranial lines studied is greater than the variation encountered in registration of natural head position.

ACKNOWLEDGMENTS

The authors are grateful to Dr. Robert B. Reed, Associate Professor of Biostatistics, the School of Public Health, Harvard University, for his collaboration in this study, and to Miss Maria Krywoshlikow, Research Assistant in Orthodontics, the Forsyth Dental Infirmary for Children, for her valuable help in the analysis of the data. Finally, thanks are due to the students of the Forsyth School for Dental Hygienists for their splendid cooperation in this undertaking.

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VIKING FUND MEDALIST FOR 1957

The distinguished scientist whom the American Association of Physical Anthropologists is honored to present tonight for the 1957 Viking Fund Medal in Physical Anthropology, is known throughout the present world. His identification with the primitive hominid, *Australopithecus africanus* Dart, carries his name backward in time to the beginning of human evolution. His place in the future is secured by the permanent significance of *Australopithecus*, the legacy of teaching and research materials he has assembled, and the diffusion of his influence through his own and succeeding generations of students. The work of Raymond Arthur Dart might thus be said to span human existence. How rich and how rare a fulfillment for a scientific career.

Doctor Dart will retire from the chair of anatomy at the University of the Witwatersrand in Johannesburg, South Africa, at the end of 1958, after 35 years of service. Jesus of Nazareth said, "No man, having put his hand to the plough, and looking back, is fit for the kingdom of God."* During his long course Dr. Dart has put his hand to many plows and never looked behind. His scientific publications began to appear in 1920 and at the end of 1957 numbered 120 titles, which reflect broad comparative anatomical and anthropological interests. The Award Committee of the A.A.P.A. noted particularly that:

He recognized the significance of the finds made at Taungs in 1925 and defended his interpretation of *Australopithecus* against wide-spread skepticism; he continued to search for and discover hominid fossils; and, thus, he has led the way for the intensive research in physical anthropology in South Africa today.

* Luke, 9: 62.



RAYMOND ARTHUR DART

Above and beyond these contributions in his special field he has played a conspicuous part in the building up of the Medical School of the University of the Witwatersrand of which he was dean from 1925 to 1943, and in medical education in his part of the world in general. He has been an important contributor in the establishment of dental education, physical therapy and occupational therapy in South Africa. He helped to establish the South African Nursing Council and to establish various journals, not least among which is the South African Journal of Medical Sciences.

The research collections which he has assembled are unique in scope and content. They include about 600 life-masks representing most of the tribes and races from the Cape to Cairo; over 500 death-masks of Africans, mostly southern Bantu speaking Negroes; and nearly 2,000 human skeletons from laboratory cadavera of which the sex, race or tribe, and hospital age are known. This human collection compares favorably with those assembled by the late Dr. T. Wingate Todd at Western Reserve University and Dr. Robert J. Terry at Washington University in this country. Dr. Dart's collections also include over 900 animal skeletons representing all vertebrate classes with a fine selection of African orders of the mammalia.

Doctor Dart's compelling personality has made him an inspiring teacher. His fascination for his students has resulted in an intriguing lore of apochryphal tales. One of these is to the effect that when in his lectures he desires to explain the effect of brachiation on the human torso, he himself will spring from the lecture platform to a ceiling pipe and brachiate along the room with gibbon-like agility, lecturing all the while. These demonstrations are described as unforgettable by those who have been so fortunate as to witness them.

It is particularly significant that many well known scientists who got their start under Dr. Dart have become distinguished not only in anatomy and anthropology, but in a variety of fields. Among them are: at the University of Cape Town, Dr. L. H. Wells, professor of anatomy and formerly reader in physical anthropology at Edinburgh University; at Makerere

College, Kampala, Uganda, Dr. Alexander Galloway, professor of anatomy and dean of the Medical Faculty, and Professor Cecil P. Luck, professor of physiology; at the University of Oxford, Dr. J. S. Weiner, reader in physical anthropology; at the University of Natal, Durban, Dr. Theodore Gillman, professor of physiology and Dr. Maureen Dale, senior lecturer in pharmacology; at the World Health Organization in Geneva, Dr. Harry S. Gear, deputy director; at the University of Stellenbosch, South Africa, Dr. Jan Toerien, senior lecturer in anatomy at the newly created Medical School; Dr. James Gear, director of the South African Poliomyelitis Research Foundation and an authority on poliomyelitis; at the University of the Witwatersrand, Johannesburg, Dr. Joseph Gillman, professor of physiology and one of South Africa's leading physiologists, Dr. Christine Gilbert, reader in embryology, Dr. H. B. Stein, professor of clinical pathology, and Dr. Phillip V. Tobias, senior lecturer in anatomy.

It would be expected that a scientist of such broad perspectives and attainments as Dr. Dart would be well known for his hospitality to guest investigators and visitors to his laboratory. There are many who attest that it would be impossible to receive kinder consideration or greater courtesy than is his custom.

Our distinguished honoree was born February 4, 1893, at Toowong, Brisbane, Australia. He received his early education at the Ipswich Grammar School in Queensland and graduated with the B.S. from the University of Queensland with honors in 1913. He was awarded the M.S. by Queensland in 1915 and received his medical degree, M.B., Ch.M., with honors, from Sydney University in 1917. The following year he was demonstrator of anatomy and acting principal at St. Andrew's College, Sydney. After this he spent a year as guest surgeon at the Royal Prince Alfred Hospital in Sydney. He first came to Europe as a captain in the Australian Army Medical Corps in 1918 and saw service in England and France. Following World War I, he remained until 1920 as senior

demonstrator of anatomy at University College, London. The year 1920-21, he spent as a fellow of the Rockefeller Foundation at Washington University in St. Louis and returned to University College London, for another year as senior demonstrator of anatomy and lecturer in histology. In 1923 he received the call to his present post as professor of anatomy at the University of the Witwatersrand.

Doctor Dart has received many honors and held high office in numerous scientific organizations. It will suffice to mention that he has been president of the Anthropological Section of the South African Association for the Advancement of Science, which awarded him its gold medal in 1939, the Anthropological Section of the Pan African Congress of Prehistory, the South African Archaeological Society and the South African Association for the Advancement of Science.

In 1949 he was a guest lecturer at the Viking Fund Seminar in New York and public lecturer for the Lowell Institute in Boston.

Recently it has been learned that there are plans for the establishment of a RAYMOND DART INSTITUTE FOR THE STUDY OF MAN IN AFRICA, to be promoted by Dr. Dart's former students and friends. It is a great joy to the American Association of Physical Anthropologists as it presents him for the 1957 Viking Fund Medal to have this moving evidence that his work and spirit will continue to benefit mankind indefinitely.

W. MONTAGUE COBB, *President*
American Association of Physical Anthropologists
— for the Association

Read at the Twelfth Annual Dinner of the Wenner-Gren Foundation for Anthropological Research for the presentation of Viking Fund Medals and Awards, Hotel Plaza, New York City, March 7, 1958.

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THE NEGROES OF CHARLESTON (S. C.); A STUDY OF HEMOGLOBIN TYPES, SEROLOGY, AND MORPHOLOGY ¹

W. S. POLLITZER ²

*Institute for the Study of Human Variation,
Columbia University*

THREE FIGURES

INTRODUCTION

With the rise of the modern concept of races as populations differing in the frequencies of certain genes, questions of the comparative meaning of "morphological" and "genetical" methods of racial analysis have inevitably followed. Both the fundamental assumptions and the practicality of application have been subjects of debate. Sanghvi ('53) undertook a comparison of the two methods in the study of several castes of India and found considerable agreement in results. The present study of the Negroes of the Charleston area, comparing populations over a wider span of miles, seeks to answer the following problems: What is the biological position of the Charleston Negro compared with the Negro of West Africa, the Negro of the United States, and the Whites of the United States? How does the answer from conventional physical anthropology compare with that from gene frequency determinations? What evolutionary factors most likely account for the biological position of the populations? And what associations may exist within an individual between racially significant morphological and genetical traits? Abnormal hemo-

¹Submitted in partial fulfillment of requirements for Ph.D. degree, Columbia University. Presented at annual meeting of Association of Physical Anthropology and American Society of Human Genetics, Ann Arbor, Michigan. April 12-14, 1957.

²Present Address: Department of Anatomy, Medical School, University of North Carolina, Chapel Hill, N. C.

globin frequencies, especially in view of the hypothesis of the relationship between sickle cell trait and falciparum malaria, may be considered a distinct study in itself.

The coast of lower South Carolina has long been known as the home of the Gullah Negro, the approximate territory being indicated in figure 1. Stoney ('30) and others have popularized the speech and personality of the colorful Negroes. After seven years of study the linguist Turner ('49) concluded that hundreds of words and much of the syntax of the Gullah dialect show evidence of its kinship to languages of West Africa. The survival of magic and other practices from West Africa among the coastal Negroes have also been noted. But no study of physical anthropology in the area has been published.

The sources of slaves imported to Charleston from 1733 through 1807, as compiled by Donnan ('35), are shown in table 1. Omitting the small numbers from the West Indies and such indefinite regions as "Guinea," the slave trade may be grouped into six regions with the percent contribution of each as indicated in the table and in figure 2. The vast numbers from the Congo and Angola contrast strikingly with the few from the "Slave Coast" (Whydah). The word "Gullah" appears to be derived from "Angola."

According to Herskovits ('41), difficulty of travel and hostility between tribes made the "thousand-mile-coffle" unlikely and infrequent. The great majority of slaves probably came from within a few hundred miles of the coast. Slaves imported to the United States after the ban of 1808 were destined primarily for the newly opened lands of the Gulf States rather than coastal Carolina. Although the Gullah isolate has been dissolving in recent decades as rural homes lose members to the cities, Negro migration into the area has been negligible. It is thus highly probable that the Negroes of the Charleston area today are the descendants of those living two centuries ago in the African areas indicated above. On the rice and cotton plantations of coastal Carolina, Negroes from different regions were blended into large and relatively isolated com-

munities, where they vastly outnumbered Whites. Phillips ('49) reasons that large plantations in which many Negroes in the fields were in little contact with the White owners is a significant factor in the development of the language and

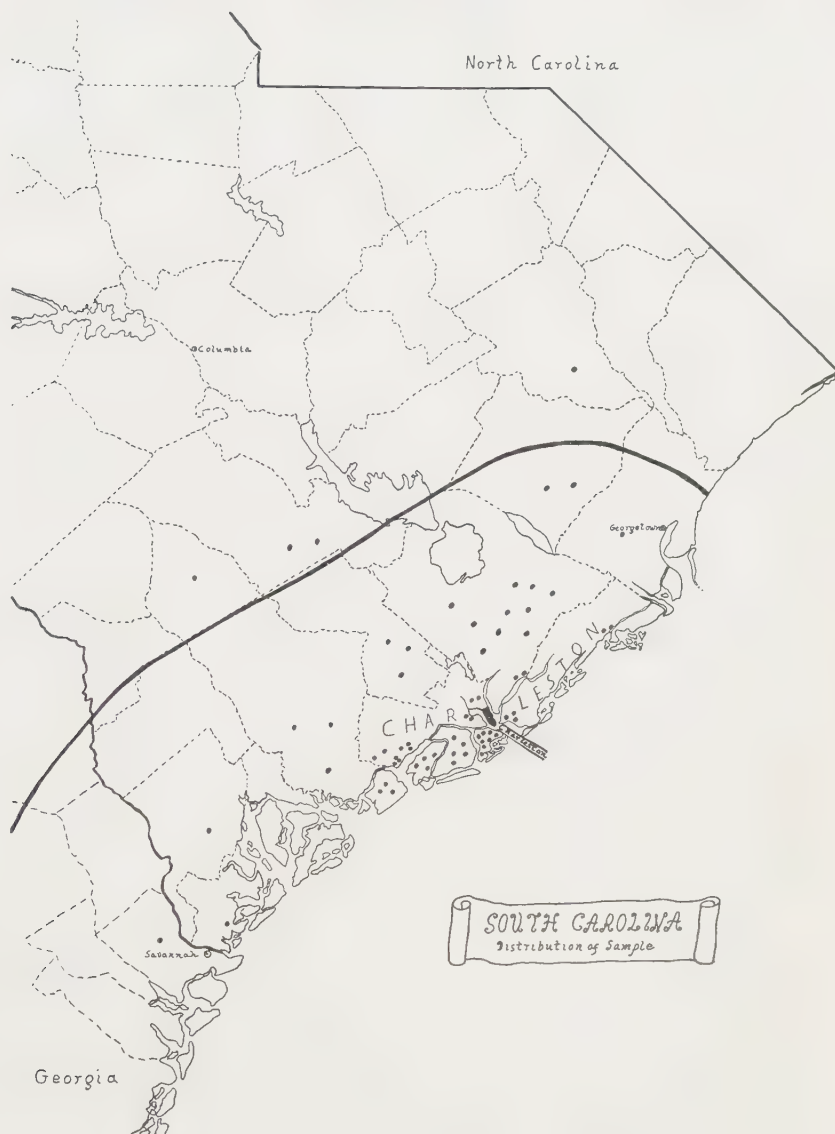


Fig. 1 Coastal Carolina, home of the Gullah Negroes.

culture unique to the Gullahs. The possible influence of this situation upon human biology will be considered presently.

THE SAMPLE

Subjects were obtained through the "colored" clinics of the Medical College of South Carolina, in Charleston, chiefly obstetrics, medicine, and less frequently orthopedics; a few came from surgery and gynecology wards of the affiliated Roper Hospital. The sample consists of 479 women and only

TABLE 1
Sources of slaves imported to Charleston 1733-1807

SOURCE	NUMBER	AREA TOTAL ¹ IN PERCENT
Senegambia		19.7
Senegal	3015	
Gambia	9468	
Windward Coast		23.3
Rio Pongo and Los Island	440	
Sierra Leone	3906	
Grain (Rice) Coast	4157	
Windward Coast	6247	
Gold Coast	8508	13.4
Whydah-Bennin-Calabar		3.7
Whydah and Bennin	992	
Calabar	1345	
Congo	10705	16.9
Angola	14618	23.0
Others		—
Guinea	1046	
East Africa, Mozambique	473	
Africa	4376	
West Indies	2175	
Unknown	1406	
TOTAL	72877	100.0

¹ The percent column for the six areas is computed after subtracting "others" from the total.

57 men, with an age range from 14 to 79. For blood studies all age groups were included; for morphology, only those 18 and above. Among females the 18 to 30 age group constituted almost half of the total.

Of the 513 subjects reporting birthplace, one-third were born in the city of Charleston, over two-thirds within the county of Charleston, and almost 95% within the coastal tier of counties in South Carolina considered the land of the

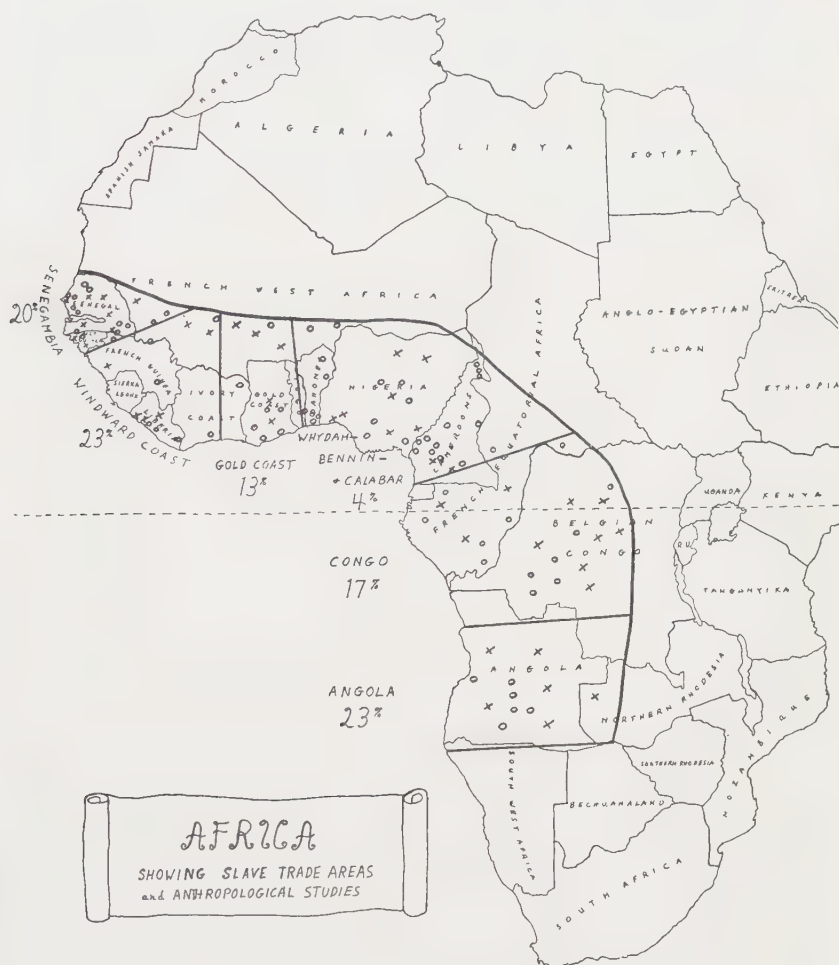


Fig. 2 West Africa, with six slave trade areas.

Gullah Negro. (In figure 1 each dot represents the approximate location of the birthplace of five subjects.) Of the parents whose birthplace was known to the subject, 11% were natives of the city, 60% were natives of the county, and 85% were from the coastal strip. It thus appears highly likely that the vast majority of subjects studied are geographically representative of the Gullah Negro. Of the subjects who reported on the birthplace of their parents, 46% named the same place for father, mother, and self. On the average the distance between the birthplace of the father and that of the mother was 25 miles; and in 73% of the cases, the two parents were born within ten miles of each other. These figures suggest that the coastal Negro of recent decades neither forms small breeding isolates nor wanders afar in search of his mate.

TABLE 2
Distribution of hemoglobin types in Charleston sample

HEMOGLOBIN	NUMBER	FREQUENCY
AA	393	.814
AS	73	.151
SS	2	.004
AC	14	.029
CC	1	.002
SC	0	.000
TOTAL	483	1.000

HEMOGLOBIN

The method of analysis followed the electrophoretic techniques of Larson and Ranney ('53), which differentiate among normal (AA), sickle cell (SS), and C (CC) hemoglobin, and any combinations of them (AS, AC, and SC). Results of the survey are presented in table 2. The high incidence of hemoglobin S is slightly above the 13.6% sickling incidence which Switzer ('48, '50) found by wet smear studies of 4066 Negroes

of the area. As shown in table 3 the Charleston gene frequencies are remarkably close to those of Africa. Wet smear determinations yield results similar to electrophoretic studies.

In view of Allison's ('54) hypothesis that falciparum malaria has an effect in maintaining the frequency of the sickle cell gene, it is noteworthy that the lower Carolina region has known malaria in endemic proportions since colonization in the late seventeenth century (Childs, '40). Although the disease is virtually non-existent today, as recently as 1937-44 McDaniel found among 58,658 Negro school chil-

TABLE 3
Comparison of hemoglobin in four populations¹

GENE	WEST AFRICA	CHARLESTON	U.S. NEGRO	WHITE
A	898	904	937	1,000
S	084	080	050	000
C	018	016	013	000
% Sickling	15.8	13.6	7.3	0.0
% Sickling calculated from gene frequencies	16.6	15.5	9.6	0.0

¹ Gene frequencies have been computed from electrophoretic studies and sickling percent from wet smear studies. Gene frequencies for Charleston are from the present study; all other figures are from the literature. A complete bibliography of the sources in this and subsequent tables is on file with Dissertation Office of Columbia University.

dren in 23 coastal counties, 2219 positive malarial smears, of which 1840 were falciparum. Although the extent of falciparum infection in the distant past cannot be determined, the large number of known death from malaria in general plus the high incidence in school children cited above suggest that it has been of prime importance in the Carolina low country. As the abnormal hemoglobin genes may have been thus influenced by selection, they will not be averaged in with the serological genes in the determination of biological distance which is to follow.

One significant finding of the present study is the age distribution of subjects with abnormal hemoglobins, as revealed

in table 4. Subjects under 30 have almost twice the frequency of abnormal hemoglobins of those over 30. If the heterozygous sickle cell hemoglobin confers a selective advantage it is difficult to explain this marked differential. Is it possible that the virtual disappearance of malaria in recent decades has destroyed the advantage of the heterozygote and even reduced it in viability to a level below that of the normals? Whatever factor is operative apparently effects both S and C hemoglobin.

TABLE 4
Association of hemoglobin and age in Charleston sample
(both sexes)

AGE	AA	AS	AC	TOTAL
14-29				
Number	181	42	9	232
Percent	.78	18	4	100
30 and up				
Number	210	26	5	241
Percent	.87	11	2	100
TOTAL NUMBER	391	68	14	473
Chi-square, 2 d.f. = 6.81				
p = .033				

SEROLOGY

Almost all subjects were typed for ABO group, subgroup, Ulex, M-N, Henshaw, Duffy, and the Rh factor. The Rh antisera routinely used were D, including D^u, C, E, c (if C was positive) and usually e (if E was positive). A smaller number were typed for Kell. Tests were made in small tubes with suitable controls, and read with a hand lens. Of the 515 blood samples 327 were typed at the Institute in New York; 188 were typed by the author in Charleston. Combined results are shown in table 5. Of the 15 Henshaw positives two were associated with M, one with N, and 7 with MN. Gene frequencies were computed by Bernstein's formulas for ABO (Mourant, '54), Wiener's for Rh ('54), homozygotes plus half the heterozygotes for M-N, and unity minus the square root of the negatives for He, Fy^a, and K.

The gene frequencies of blood types of Africans, Charleston Negroes, American Negroes, and Whites are presented in table 6. In nearly all genes a gradation from Africans to Whites through the Charleston and American Negroes is

TABLE 5

Distribution of blood types in Charleston sample

PHENOTYPE	NUMBER TESTED	NUMBER POS.	FREQUENCY ¹
ABO	514		
A ₁		67	.1304
A ₂		46	.0895
B		127	.2471
O		256	.4980
A ₁ B		5	.0097
A ₂ B		13	.0253
M-N	515		
M		128	.2485
MN		268	.5204
N		119	.2311
Rh	515		
D _{cc} ee		291	.5650
D _{cc} Ee		21	.0408
D _{cc} EE		6	.0116
D _{cc} E/		34	.0660
DC _{cc} ee		73	.1417
DC _{cc} Ee		3	.0058
DC _{cc} E/		6	.0116
DCC _{cc} ee		12	.0233
DCCEe		1	.0019
DCCE/		1	.0019
DC/ee		1	.0019
DC/E/		1	.0019
D ^u _{cc} ee		17	.0330
D ^u _{cc} Ee		1	.0019
D ^u _{cc} E/		1	.0019
D ^u C _{cc} ee		4	.0078
D ^u CC _{cc} ee		1	.0019
d _{cc} ee		34	.0660
d _{cc} E/		1	.0019
dC _{cc} ee		6	.0116
He	471	15	.0318
Fy ^a	515	16	.0311
K	119	3	.0252

¹ Gene frequencies are presented in table 6.

evident. To measure the biological distance between the populations the Chi-square method of Sanghvi ('53) was employed, based on:

$$\chi^2 = \frac{100 \sum_{i=1}^n \sum_{j=1}^r \frac{(p'_{ij} - q_{ij})^2}{q_{ij}} + \frac{(p_{ij} - q_{ij})^2}{q_{ij}}}{\text{Total number of degrees of freedom}}$$

where n = number of discrete characters, each character having two to r classes; p_{ij} is the proportion of j -class of i -char-

TABLE 6
Comparison of gene frequencies in four populations

	WEST AFRICA	CHARLESTON	U.S. NEGRO	WHITE
p	157	137	169	260
q	155	153	133	060
r	688	710	698	680
m	535	509	510	530
n	465	491	490	470
R _z	000	004	004	001
R ₁	094	087	143	422
r'	040	022	027	009
R ₂	056	069	102	143
r''	000	004	004	013
R ₀	586	558	465	023
r	224	257	255	389
He	063	016	016	000
F _y ^a	000	016	140	413
K	004	013	018	042

acter for one population and p'_{ij} for another; and $q_{ij} = (p_{ij} + p'_{ij})/2$. In the distances presented in figure 3, compared with the American Negro, the Charleston Negro appears closer to Africa and farther removed from the White-African axis.

MORPHOLOGY

Skin color was observed in the scapular region and recorded in terms of Gates' ('49) chart. Prognathism was recorded as none, slight, moderate, or marked, or half grades between, transformed for computation to a scale from 0 to 6. The following measurements were made according to the

technique of Martin ('28), whose number follows in parentheses: nose length (21) and width (13), lip thickness (25), face length (18) and width (6), stature (1), and sitting height (23). Also made but not included in the analysis were hip and shoulder measurements (too inaccurate) and hair color and form (uniformly black or gray and usually artificially straightened). The results of the morphological study are compared with findings in the other three populations in table

TABLE 7
Comparisons of morphology in four populations¹

TRAIT	MALES				FEMALES			
	West Africa	Charleston	U. S. Negro	White	West Africa	Charleston	U. S. Negro	White
Skin color	2.2	3.0	5.0	9.0	2.2	2.8	5.0	9.0
Nose length	47	57	53	54	42	55	51	51
Nose width	44	46	41	35	39	42	39	32
Lip thickness	25	21	21	16	24	22	19	15
Face length	113	126	123	121	105	119	117	112
Face width	135	139	139	140	127	132	132	130
Prognathism	4.8	3.4	3.0	0.0	4.3	3.7	3.0	0.0
Standing height	1678	1675	1712	1738	1557	1593	1606	1623
Sitting height	836	856	872	911	768	822	830	863

¹Skin color numbers refer to Gates' chart. Prognathism is on a scale from 0 = none to 6 = marked. All other measurements are in millimeters. Techniques are explained in the opening paragraph of the section on morphology.

7. The numbers for skin color in Charleston may be translated as fairly dark chocolate and those for prognathism as just less than moderate. Although some gradation from Africa to Whites is shown in most of the traits, precise measure of distance is complicated by variances and correlations between traits. The generalized distance, or D^2 , of Mahalanobis ('49) has been used to allow for these factors. The procedure rests upon the formula: $D^2 = \sum \sum w^{ij} d_i d_j$ where w^{ij} is the inverse of the matrix of covariance and d is the difference between

two populations with respect to each continuous morphological trait employed. The method is accurate only where the traits are normally distributed, the standard deviations and correlations are similar in the populations compared, and the populations themselves live under similar environmental conditions. All traits except prognathism are normally distributed in the Charleston sample. As the standard deviations and correlations are but rarely given for the populations in the literature, those for the Charleston series have been used. The physical and cultural environment in Africa and America is obviously different. Thus, the present analysis is at best an approximation to the method of Mahalanobis. The figures suggest an unreasonable discrepancy between nose and face lengths in Charleston and in Africa. Many workers in Africa were apparently locating nasion too low (perhaps using sellion as the superior point of the measurements) and the author was locating it too high. These two dubious measurements have therefore been omitted from the analysis. Since the discriminant coefficient is given by: $l_i = \sum d_j w^{ij}$ for any trait, the difference in each trait between two populations was multiplied by the appropriate item in the inverse covariance matrix. The sum of products is the discriminant coefficient, an indication of the value of that trait in differentiating between the populations considered. The difference in each trait was next multiplied by its discriminant coefficient, and the sum of these products is the D^2 . The square root of this value is the distance between two populations. The results of these computations, made for each sex for each of the 6 possible distances, are shown in figure 3. As the findings for males and for females were reasonably similar, they were averaged. The Charleston Negro again appears closer to Africa than the average American Negro and further removed from the White-African axis.

A comparison may now be made between the "genetical" and "morphological" methods of distance ascertainment. The two sets of distances may be transformed into mean units;

each of the 6 morphological distances is divided by the average of the 6, and the genetical distances are treated in a comparable manner. It is evident from the results shown that distances derived by both methods are essentially similar.



Fig. 3 Distance between Four Populations by Morphology and Serology In Mean Units.

ASSOCIATIONS BETWEEN MORPHOLOGICAL AND GENETICAL TRAITS

To compute a "morphological score" for an individual, the discriminant coefficient between Africans and Whites for each trait may be multiplied by the individual's value for each trait and the products summed. Females in the Charleston sample were arranged according to their morphological

scores and the sample divided at the mean into moieties containing approximately equal numbers. The "more Negroid" fractions were then compared by Chi-square tests as to the frequency of certain genetical traits. Those selected as showing marked differences between Negroes and Whites were the abnormal hemoglobins AS and AC, Group B, Rho (D_{ccce}) plus all variants (Dⁿ), Henshaw, and Duffy. The results are

TABLE 8
Association of morphology and genetic traits by chi-square value
(adult females only)

TRAIT	Hb	Fy ^a	B	Rh ^o + D ^u	He	TOTAL
Deg. Freed.	2	1	1	1	1	6
By discriminant function ¹	0.7	2.7	3.0	0.3	0.2	6.9
Prognathism	3.4	3.9*	0.1	1.8	0	9.2
Lip thickness	1.5	3.7	3.8*	0	0	9.0
Nose width	5.4	0	1.4	0	0.2	7.0
Sitting height	4.6	1.1	0	1.0	0.3	7.0
Nose length	4.6	0	0.5	0.5	0	5.6
Face length	1.4	1.0	2.1	0	0.4	4.9
Skin color	0.1	3.8*	0.9	0	0	4.8
Standing height	0.8	0	0	2.1	0.2	3.1
Face width	1.2	0	0	0.2	0	1.4
Deg. Freed.	18	9	9	9	9	54
Total (9 traits)	23.0	13.5	8.8	5.6	1.1	52.0

* Significant at .05 level.

¹ The Discriminant Function is a composite measure of negroidness based on all of the nine traits listed. It is found by multiplying a coefficient (the value of any given morphological trait for Negro-White differentiation) by the individual's score for each trait, and summing the products.

presented at the top of table 8, which shows Chi-square and p values and degrees of freedom. The genetical trait showing the highest Chi-square value is B, followed closely by Fy^a; the hemoglobins, Rh and He are lower.

To test the association of genetical traits with each morphological trait, the female subjects were ranked by each particular morphological trait and divided at the mean into two moieties. The genetical data were counted and tested for

significance, results of which are also shown in table 8. The only associations which are significant at the five percent level are the Fy^a blood factor with prognathism and skin color, and Group B with lip thickness. The small value of association of Rh_0 (and D^u) with most Negroid morphological traits is noteworthy. The total for each morphological trait is in the column at the right, and the total for each genetical trait in the row at the bottom, both ranked by descending value. If the genes listed at the top of the table are indicative of negroidness, then the value of any morphological trait for racial differentiation may be read from the total column at the right. By such a test prognathism and lip thickness would be superior. If the morphological traits listed are valid indicators of negroidness, then the value of any given gene may be read from the bottom line. According to this procedure, Fy^a is the most important genetical trait for differentiation, followed by B and the abnormal hemoglobins, with Rh_0 and Henshaw least important. This rating of genes by summation of their value with individual morphological traits yields a picture similar to, but not identical with, the results found through the discriminant function.

DISCUSSION

On the basis of morphological and serological findings the Charleston Negro has been compared with the West African Negro, the American Negro, and Whites to determine the degree of similarity among them. What biological meaning can be assigned to the distance thus computed? Although the aim of the calculations is the measurement of actual genetic kinship, both genetical and morphological methods fall short of this goal. In theory the blood type frequencies dependent upon single genes inherited in a known Mendelian manner, fully expressed, and not subject to environmental modification *within the individual*, should be perfect indicators of the degree of affinity. Such genes, especially those showing wide variations in frequency among the populations considered, appear to be ideal for the modern genetic concept of race.

Yet the monogenetic nature of the blood type genes permits them to be readily affected by random fluctuations and sampling error. The same frequency of a gene may occur in diverse and obviously unrelated people, while groups as closely akin as two North American Indian tribes may show a striking difference. Only recently has a start been made in unravelling the possible role of selection in the blood types. Other major drawbacks to the genetical approach at the present time are the complexities of technique and the rather few "gene" traits known which occur in suitably high frequencies. Nevertheless, a large number of blood factors should yield a fairly accurate measure of biological relationship, especially where adequately supported by data from such other disciplines as history, archeology, or physical anthropology. The totalled Chi-square calculations based on serology may be considered a reasonable approximation to genetic kinship among the populations involved.

The morphological traits present a different kind of problem. In addition to the difficulty of precise measurement, no simple pattern of inheritance is known for these polygenic traits. Many if not all are subject to environmental modification *within the individual*, skin color, hair color, and hair form being especially malleable. Selection through many millenia probably plays the major role in the formation of most such racial traits; chance fluctuations should wield relatively little influence. Many morphological features, distinctive among the populations of the world with little or no overlap, have been used by anthropologists for over a century in racial classification. In the absence of known artificial deformation or time enough for appreciable natural selection, morphology should yield a reasonably accurate index of relationship. The generalized distance, allowing for intercorrelations and range of variation of the traits, should provide the best estimate.

Satisfactory agreement of the two methods is indicated by the present study.

The major evolutionary factor most likely responsible for the biological positions of the populations appears to be hybridization between West Africans and Whites. This phenomenon is indicated by the gradation in serological and morphological factors. Among the blood factors this effect is well illustrated by the ABO, Rh, Kell, Duffy, and Henshaw systems, in addition to the abnormal hemoglobins. Of the morphological traits, skin color, prognathism, lip thickness, stature, and sitting height present a similar picture. The implication of the data and the diagram is that, although both intermediate groups have undergone admixture with Whites, the Negroes of Charleston have received far less White genes than Negroes elsewhere in the country. That the average American Negro shows evidence of significant admixture is known from the studies of Herskovits ('30) in morphology and genealogy and those of Glass ('55) in genetics. Coon, Garn, and Birdsell ('50) even consider them distinct enough to be called a separate "race."

Why should the Gullah Negro have less genetic contribution from Whites than those Negroes elsewhere in the United States? The ratio of the races on the low-country plantations may provide one answer. Just as the social situation molded the language and culture characteristic of the Gullah Negro, it may have played a dominant role in shaping the physical man as well. Besides offering less opportunity for mixture, the social situation probably created a psychological factor opposing it. Wherever Negroes are in close association with a dominant White society in large numbers, White physical traits seem to be held at a premium. Those Negroes with indications of Caucasian admixture have greater opportunities for transmitting their genes. But in isolates composed overwhelmingly of distinctly Negroid individuals a sense of social cohesion develops which militates against those showing signs of admixture. Mate selection, operating on visible traits, might be strong enough to discourage miscegenation or to lead to the migration of hybrids away from the area. Although documentary proof is lacking, it is likely that such

a mechanism has had significant influence among the Negroes long isolated in the coastal counties of lower South Carolina.

The Charleston Negroes are not only nearer to Africa biologically; they are also somewhat removed from the African-White axis relative to the general American Negro. This fact suggests that somewhat different parental stocks may have fused in the formation of the Negroes of Charleston and those elsewhere in the United States. The provenance of Negroes brought to America, other than to Charleston, is inadequately known. Areas to the south and east in Africa were apparently engaged in the slave trade, especially in the illegal operations following 1808. Even within West Africa the relative contribution of tribes to the Gullahs may have differed significantly from that to other Negroes of America. The White component which fused with the Negro may also have varied appreciably in different parts of America.

The question of Indian admixture with the American Negro has been raised by Herskovits ('30) and by Glass ('55). The former, basing his argument chiefly on genealogy, suggests a significant degree of Indian contribution to the amalgam. The latter, relying primarily upon the serological genes, concludes that the Indian flow has been virtually negligible. In frontier days many opportunities existed for miscegenation, and a few communities of today bear witness to such racial fusion. Some physical and verbal evidence for Indian admixture came to the author's attention during a survey of the sea-island area of Carolina and Georgia. Although Indian gene frequencies in general (as reported by Mourant, '54) are compatible with the theory that that race did contribute genes to the American Negro, too little information is available for a precise statement of the degree of Indian influence. Serological studies are almost entirely of tribes beyond the range of possible fusion with Negroes, and these exhibit wide variability.

As the difference in degree of admixture and in ancestral stocks may not be the sole explanation of the divergence of

Charleston from other American Negroes, other evolutionary factors should be considered. Could natural selection produce significant differences in the two hybrid populations? It is difficult to conceive of environmental agents, differing between coastal Carolina and the rest of the nation, potent enough to create detectable differences in a mere dozen generations. The relative isolation of the Gullah Negroes on large plantations through one or two centuries appears to offer an ideal situation for the operation of genetic drift. Until recent decades the vast majority of the native Negroes of the coastal strip probably spent their entire lives within a few miles of their birthplace. But any random fluctuations in gene frequencies thus produced should tend in varying directions within any small isolate. The 25-mile average distance between birthplace of the subject's parents in the present sample suggests that any deviations produced in the isolates of the past would be cancelled out in the formation of the larger gene pools of recent generations. It therefore appears likely that neither natural selection nor genetic drift has played an appreciable role in the biological position of the Charleston Negro.

The significant association between morphology and the blood factor genes is probably due to hybridity. If genes for a negroid physical trait and those for a negroid blood factor enter a mating together, they would tend to remain together, especially if they are on the same chromosome. If they are close together on the chromosome many generations might be required to achieve random association. Association between morphology and blood factors should thus yield some indication of the position of the genes on the chromosomes. However, the polygenes for morphological factors are unknown and of unequal value in differentiating the races; nearly all of the negroid serological genes and hemoglobin genes occur in only a minority of Negroes; and the statistical procedure used to measure the relationship is affected by chance, especially in small categories. Thus no reliable estimate of the chromosomal relationship between morphological

and other genes can be made from the present data. Ideally racial analyses should include a large battery of both morphological and genetical traits. Such an approach not only permits each method to serve as a check on the other; it might also point the way toward a better understanding of the chromosomal or physiological association between traits.

SUMMARY

Data have been presented on approximately 500 Gullah Negroes of the Charleston, South Carolina, vicinity. Comparisons have been made with natives of West Africa, average American Negroes, and Whites. Values for abnormal hemoglobin in the Charleston sample are close to African ones and may have been maintained at this high level through the action of falciparum malaria. The degree of similarity between Negroes of Charleston and other populations has been analyzed by two methods: Sanghvi's Chi-square of the gene frequencies for blood types and Mahalanobis' generalized distance for the morphological traits. Results of the methods are quite similar; both show that the Charleston Negro is distinct from, and closer to Africans than, the general American Negro. Hybridization to a lower degree appears to be the major cause of the biological position noted. Study of the association of genetical and morphological traits within the individuals tends to confirm hybridization and suggests traits useful in racial study.

NOTES

Tables of data on hemoglobin, serology, and morphology collected from the literature on West Africans, American Negroes, and Whites are on file with the Dissertation Office of Columbia University. On the map of West Africa each circle or cross indicates the approximate location of one morphological and one serological study respectively. An effort was made to include all known studies on Negroes within the slave trade regions, omitting pygmies and those with obvious Caucasian admixture and a few studies of ancient

vintage, doubtful techniques, small sample, and those giving no means. Sickling and blood type data are based on Mourant's ('54) and Boyd's ('39) compilations, but original sources have been checked wherever possible and additions made wherever necessary. All genetical data were reduced to gene frequencies. Bernstein's correction was applied to ABO frequencies which did not total between .999 and 1.001.

To obtain an average for any value in Africa, the available studies within each of the six regions were first weighed by sample size (which emphasizes the more accurate modern studies with large samples) and averaged. Then the 6 means for the trait were averaged according to the contribution of each region to the Charleston slave trade. Figures for American Negroes and Whites were averaged with equal weight for each study, with the exception of the serological studies in New York City which were first averaged by sample size to yield a single study.

Wide variations in hemoglobin values in Africa tend to cast doubts on the validity of the data from the literature, but close agreement of the African average by electrophoresis with that by wet smears of sickling lends substantiation to the figures. Except for ABO groups blood typing data are still too scarce in most of Africa to provide reliable estimates. Studies on American Whites and Negroes are purposely aimed at sampling primarily the South. As insufficient serological data, other than ABO, are available on Southern Whites, who are about 85% of English stock, English blood type frequencies have been substituted. The similarity of the two in ABO frequencies tends to justify the procedure. Skin color has been subjected to such a bewildering array of scoring techniques that any estimate for a large territory is unavoidably poor. An effort was made to translate verbal and numerical estimates to numbers of Gates' chart. Evaluation of prognathism is equally difficult. The scarcity of morphological data on African females is also regrettable.

In using Sanghvi's measure of genetical distance, a $2 \times r$ contingency table was set up for each different blood type sys-

tem. As the "expected" value for each class is the average between the two "observed" values, the difference between observed and expected will be the same in any one class. Thus it is simpler to compute half of the Chi-square value. Since the number of genes compared is the same for all four populations, the number of degrees of freedom can be ignored. The square root of the sum of all the Chi-square values yields the distance between any two populations. ABO, MN, Rh, Fy^a, He, and K have been employed as separate systems; using within the Rh system 4 major genes (R^1 , R^2 , R^0 , and r) and the sum of R^z , r' , and r'' . As sub-group data are scarce, often unreliable, and highly variable in the 4 populations, they have been omitted in the calculations.

In the diagrams of distance morphology is an accurate representation; serology has been slightly distorted in order to convert a three-dimensional figure to a flat surface.

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REVIEW

MANUAL DE ANTROPOLOGÍA FÍSICA. By Juan Comas. 698 pp.
Fondo de Cultura Economica, Mexico, 1957.

The need for a good textbook on physical anthropology in Spanish has long existed. The reviewer was impressed by this need in 1945 when he gave a seminar in osteometry at the Escuela Nacional de Antropología in Mexico City. Just to be on the safe side he took along a photostatic copy of the osteometric section from Martin's Lehrbuch. As it turned out, this standard work was not readily available in Mexico City and few of the students had seen it. At that time, too, Pérez de Barradas had not issued his Manual de Antropología, and when it appeared (Madrid, 1946) it was to prove inadequate.

At last the deficiency is supplied. Juan Comas has produced a Manual, which, considering the immense difficulty involved in covering such a broad field as physical anthropology, and the need to write for students with poor and heterogeneous preparation, is eminently successful. No other work of this nature does such even justice to the knowledge produced in both hemispheres; none is so judicious and well balanced in its treatment of the various subdivisions of physical anthropology; and naturally, none is more up-to-date. This is not surprising, considering Comas' European background and training and his long experience in Mexico both in teaching and in editing.

Comas has produced an up-to-date book not only by citing recent publications but by stressing the points of view widely held today and contrasting them with those of the past. Yet he has wisely tempered this emphasis on the new by giving due attention to historical antecedents. Indeed, his historical sections constitute about the best history of physical anthropology available. From this historical perspective Comas points out, for example, that

Washburn nos muestra algunos contrastes entre las que denomina Antropología física clásica y nueva Antropología física, aunque para nosotros *no hay límites precisos entre ambas; se trata de etapas necesarias en la génesis de una ciencia y, como veremos, ello no supone en modo alguno cambios radicales y muchos menos un balance negativo del pasado* . . . (p. 36. Italics supplied.)

A textbook can be up-dated by de-emphasis as well as by emphasis. Thus, the Manual unlike some older texts cannot be mistaken for a work on anthropometry, primatology or raciology; it contains no pic-

tures of measuring instruments, lower primates or human races. The omission of such pictures is in keeping with the author's desire to give proper balance to his book and (probably) to indicate the limited attention being given at present to these fields. One might question whether such de-emphasis does not defeat the objective of supplying the needs of students who have limited preparation, especially in biology. Comas seems to have decided, however, that students can find illustrations in the references supplied and that they should not be forced to pay a higher price for the Manual, which would have been necessary doubtless, if it had included half-tones (all illustrations, by the way, are text-figures).

The question of what should be included or omitted from a work of this type—be it pictures, references, or subjects—requires special knowledge and wisdom on the part of the author. Comas has done remarkably well in all these matters. His selection of references is especially good. Of course, this does not mean that all of his colleagues will find all of their pet titles included. Yet often they will find cited instead general articles in which at least their points of view are taken into consideration. After all, the word "manual" as used in Spanish, means a compilation of the most substantial material in a field, and this gives the compiler great leeway.

In the presentation of the detailed subject matter, on the other hand, there may be more basis for criticism, simply because the field is so large that no one can speak with the same authority throughout its range. Yet only in the field of statistics does Comas acknowledge his limitation, in this case calling on Felipe Montemayor for aid.

Perhaps at this point the chapter headings should be listed with indication of the space devoted to each: 1, Generalities (62 pp.); 2, Origin and evolution of man (38 pp.); 3, Heredity (74 pp.); 4, Growth (64 pp.); 5, Somatology (57 pp.); 6, Biotypology and constitutional types (42 pp.); 7, Craniology, osteology (71 pp.); 8, Paleo-anthropology (104 pp.); 9, Racial systematics and human groups (57 pp.); 10, Utilization and teaching of physical anthropology (41 pp.). Appendices: 1, The Monaco Agreement; 2, The Geneva Agreement; 3, The *Unesco* statement on race (1951); 4, Record form for somatoscopic examination; 5, Record form for somatometric examination; 6, Record form for craneometric examination; 7, Record form for the Viola type of biotypologic examination. Bibliography by subject.

For a detailed examination of the text the reviewer turned to the section on craniometry. Here he found that Comas lists only the most important landmarks and measurements. Probably because of space limitations he has not tried to be as exhaustive in this regard as

Martin. However, here and there the reviewer felt unhappy about the way in which some of the directions are presented. For example, the technique of taking cranial capacity, about which volumes have been written, is stated in one sentence: "Para medir la capacidad se cierran los agujeros craneales con algodón o cera, y se rellena cuidadosamente el cráneo; luego se vierte el contenido en una probeta graduada, la cual nos da el volumen en centímetros cúbicos." Then follows a half page of formulae for calculating capacity from external skull measurements. The student is not warned that the formulae can yield figures in error by as much as 200 cc, and that improper measuring techniques also can yield equally large errors; nor is he urged to perfect a proper technique and to try whenever possible for the direct measurement rather than the calculated one. However, the fact that the fault selected as typical is a minor one is further evidence of the quality of this book.

Comas is to be congratulated on his accomplishment.

T. D. STEWART
U. S. National Museum

THE PATHOGENESIS OF ARTIFICIAL CRANIAL DEFORMATION ¹

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NINE FIGURES

INTRODUCTION

Cephalic growth continues to interest diverse scientific disciplines. It is useful to regard the head as a functional matrix consisting of many series of interacting functional units (van der Klaauw, '46; Starck, '53). For example, one major series includes the calvaria, dura mater, and skull base, while the outer table, diploe and inner table of the frontal bone form another minor series. The nature of the mutual interaction between some of these functional units has been experimentally demonstrated in laboratory animals (Moss, '54, '55, '57a, '58a, '58b). Such data, of intrinsic value, are not directly applicable in the field of human cephalogenesis. While extensive longitudinal and cross-sectional human cephalic growth studies provide normative data, demonstration of such functional interactions in man is possible only by study of either congenitally or artificially deformed heads. Coincident with a study of the former condition, the morphological alterations of artificially deformed skulls were analyzed. The correlation of these induced changes with specific external forces yielded a first approximation of the interactions of functional cephalic units in both normal and congenitally deformed heads.

¹ Aided, in part, by a grant (B-965 C-2), National Institute of Neurological Diseases and Blindness, National Institutes of Health, Public Health Service.

MATERIALS AND METHODS

Lateral skull roentgenograms of 65 artificially deformed skulls of North and South American Indians were obtained at the Division of Physical Anthropology of the National Museum and the Department of Anthropology of the American Museum of Natural History. The origin of this material is given in table 1. A control series consisted of 24 skulls of Northwest Coast Indians (Kwakiutl). Additionally, 54 films of white infants, diagnosed as possessing "postural flattening," were obtained from Babies Hospital, Columbia University-Presbyterian Hospital.

TABLE 1
Geographic distribution of deformed skulls

	OCCIPITAL OBLIQUE	OCCIPITAL VERTICAL
Northwest Coast Indians Chinook	14	12
Indians of the Altiplano (Peru-Bolivia)	12	11
Louisiana Indians	—	8
Indians of the Dominican Republic	2	6
Totals	28	37

The method of analysis of these films and normative data for white skulls of various ages have been presented extensively elsewhere (Moss and Greenberg, '55; Moss, '56, '57b). In essence, the endocranial plane of the clivus is a reference plane upon which are projected the planes representing the posterior roof of the orbit (lesser wing of the sphenoid) and the planum sphenoidale. The angles formed by these planes are recorded as the orbital and planum angles respectively. Orbital angle values of the posturally flattened infants were corrected for by assuming that individual angular deviations would remain constant in each child. The mean normal orbital angle decreases 14° with age (Moss and Greenberg, '55). This mean correction factor was subtracted for each child and direct comparison with adult values was made.

In addition the ectocranial surface of the occipital squama, sella turcica, palatal plane (anterior-posterior nasal spines),

plane of the foramen magnum (basion-opisthion) and petrous crest of the temporal bone were traced. The clivofoaminal angle was measured. All tracings were then registered along the clival reference plane at a point tangent to the lower border of the sella and tracings of the petrous crest transferred to a master tracing.

The outstanding diagnostic characteristic was the shape of the occipital squama. Two types were clearly discernable, termed "oblique" and "vertical." This referred to the orientation of the occipital squama as a whole relative to the facial skull (i.e., relative to the parallel planes of the planum sphenoidale and of the palate). In the oblique type the occipital squama was canted obliquely to the facial planes, while in the vertical type the plane of the occipital squama was vertical with respect to the facial skull planes (figs. 1, 2, 3). Differ-

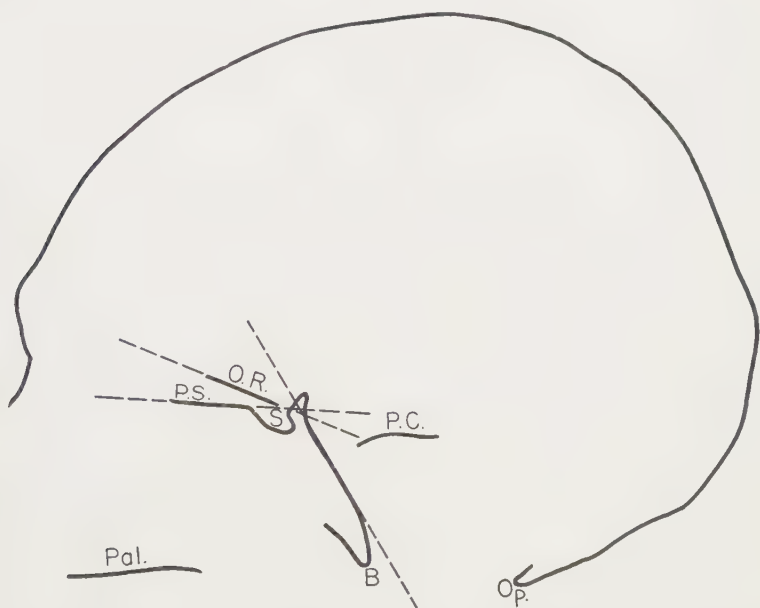


Fig. 1 Tracing of a roentgenogram of a normal, non-deformed American Indian skull. (B) basion; (Op) opisthion; (Pal) plane of the hard palate; (P.C.) petrous crest of the temporal bone; (S) Sella Turcica; (O.R.) orbital roof, lesser wing of the sphenoid bone; (P.S.) planum sphenoidale. The method of determining the orbital and planum angles is indicated in the figure.

ential subclassification of these two types in terms of coexistent deformations or of method of deformation did not affect the value of the original diagnosis (see Dembo and Imbelloni, '38).



Fig. 2 Superimposed tracings of roentgenograms of the normal skull, shown in figure 1 (interrupted line) and of a skull with the Vertical types of artificial deformation (solid line). These tracings were registered along the planum sphenoidale and the anterior curvature of the sella turcica. Note the changes in the position of the petrous crest and of the plane of the foramen magnum, in addition to the obvious calvarial alterations.

Literature on artificial cranial deformation deals with two aspects of the problem; classification and morphologic description. The former has been thoroughly reviewed by Dingwall ('31) and by Aichel ('33); the latter by Falkenburger ('38), Oetteking ('24), Queveda ('46), and in a long series of papers by Imbelloni (see Dembo and Imbelloni, '38). None of these papers considers the problem in relation to the skull as a functional unity, and none of them considers the patho-

genesis of deformation in terms of the growth patterns of the constituent cephalic units. The present study is intended to fulfill these requirements.



Fig. 3 Superimposed tracings of the normal skull (interrupted line) and of a skull with the Oblique type of artificial deformation (solid line). These tracings were registered as in figure 2.

RESULTS

Controls. The non-deformed control series of Adult North-west Coast Indians was first compared with a series of normal American whites. The mean orbital angle of the Indian group was significantly greater. This confirms older data reporting this group as having a "high orbit" (hypsophthalmia) (table 2).

Vertical deformation. The planum and clivo-forminal angles were significantly smaller than the Indian controls. The orbital angle was not significantly different.

Oblique deformation. Both the mean planum and orbital angles were significantly larger than control values. The clivo-foraminal angle was significantly smaller.

"Postural flattening." When compared with the White control sample the mean alteration of planum and orbital angles of these children were identical with those of the vertical deformation series.

Petrous crest changes. The registered tracings of the petrous crest of vertical and horizontal deformations and of the controls are shown in figure 4, with the ranges of position

TABLE 2
Basal angular values of deformed and non-deformed skulls

	NO.	PLANUM ANGLE	ORBITAL ANGLE	CLIVO-FORAMINAL ANGLE
White-Adult (Normal)	61	120.5 \pm 1.10	138.1 \pm 1.20	—
Indian-Adult (Normal) Kwakiutl	24	121.4 \pm .79	148.1 \pm 1.08	127.0 \pm 1.14
Artificial deformation (occipital oblique)	28	126.6 \pm 1.20	159.1 \pm 1.26	122.8 \pm 1.21
Artificial deformation (occipital vertical)	37	114.4 \pm 1.56	145.5 \pm 1.26	121.6 \pm 1.25
Postural flattening (white infants)	54	114.5 \pm 1.05	140.3 \pm 1.07	—

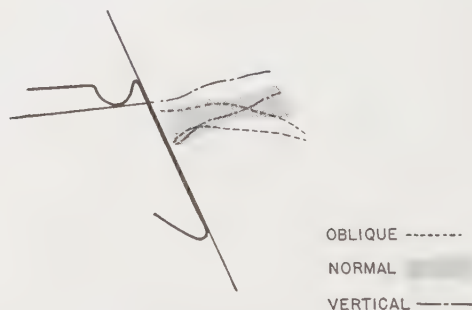


Fig. 4 The ranges of petrous crest position in normal and artificially deformed skulls are shown in superimposed tracings of roentgenograms registered on the clivus and on a line tangent to the lower border of the sella turcica. Note that the medial ends (anterior) of the crest are virtually identical in range in both of the deformed types and in the normal. The lateral (posterior) ends of the crest have an elevated range in the Vertical type of deformation and a depressed range in the Oblique type, both in relation to each other and to the normal sample.

shown for each group. While the position of the medial (anterior) point of the ridge was quite similar in all three groups, the contour and position of the lateral (posterior) portions of the crest differed quite significantly. In the vertical type of deformation the crest rose; in the oblique type it was depressed.

DISCUSSION

Artificial cranial deformation is produced by the dynamic distortion of the normal vectors of infantile neurocranial growth through the agency of externally applied forces. The deforming apparatus cannot alter the magnitude of intrinsic growth, but it does alter its direction. Analysis of the two types of deformation must be based on knowledge of normative infantile neurocranial growth data. Skull growth is coordinated with and response to the growth of the enclosed contents which are either protected or supported by the skeletal tissues. The magnitudes and directions (i.e., the vectors) of endocranial and neural growth are virtually identical. Neither the direction nor the magnitude of these intrinsic forces are precisely known. We do, however, have data illustrating the results of their actions.

Postnatal endocranial growth changes have been detailed by Dabelow ('31), Stadtmüller ('43) and by Bergerhoff and Martin ('54). The first two papers graphically report the simultaneous dimensional alterations of cerebral fossae in childhood (fig. 5). The latter reports a series of mean linear and angular values which give a very clear conception of the rotations of endocranial components with age. We have previously reported on postnatal changes of skull base angulation noting decreasing orbital and constant planum angles during this period (Moss and Greenberg, '55).

In essence, all these papers reported that infantile lateral and vertical endocranial increments are simultaneously accompanied by a relatively great backward and downward rotation of the occipital region (fig. 6). All of these changes represent a continuation of relatively more rapid prenatal

growth processes (Kummer, '52; Hochstetter, '39; Moss, Noback and Robertson, '56; Noback and Moss, '56).

The occipital region has the greatest postnatal neurocranial growth rate. This is reflected in the relative growth rates

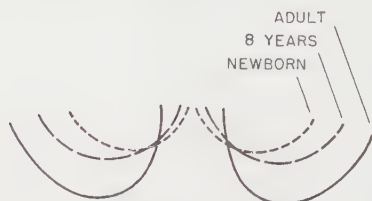


Fig. 5 The simultaneous downward and lateral expansion of the middle cerebral fossa with growth is diagrammatically shown in three coronal tracings registered at the sella turcica (after Dabelow, '31).

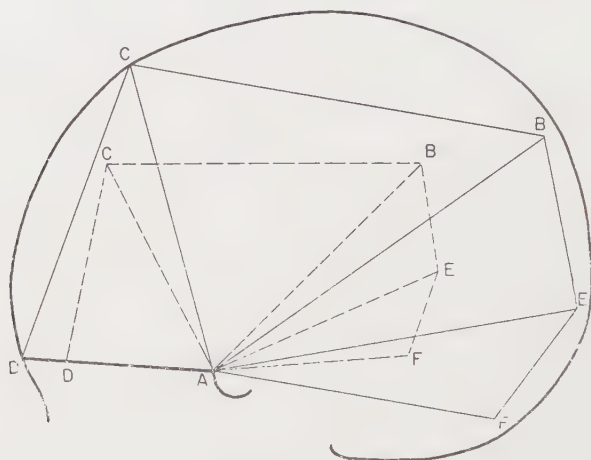


Fig. 6 A sagittal representation of the dimensional and angular growth changes of certain neurocranial landmarks in the White male (solid line = 20 years, interrupted line = 2 months). (A) tuberculum sellae; (D) most anterior endocranial part of the anterior cerebral fossa in the mid-line; (C) coronal suture; (B) lambdoid suture; (E) confluens of sinuses; (F) planum nuchae. Adapted from Bergerhoff and Martin ('54).

of both the occipital bone and of the cerebellum (Noback and Moss, '56). The posterior cerebral fossa, lying subtentorially and containing both the cerebellum and brain stem, expands laterally, while markedly rotating downward relative

to the facial skull. The angular growth changes of the plane of the foramen magnum strikingly demonstrate this movement. The total downward and backward rotation of this plane throughout life is about 28° relative to the horizontal semicircular canal (fig. 7) (Fenart, '53). The prenatal portion of this rotation has been reported, relative to other reference

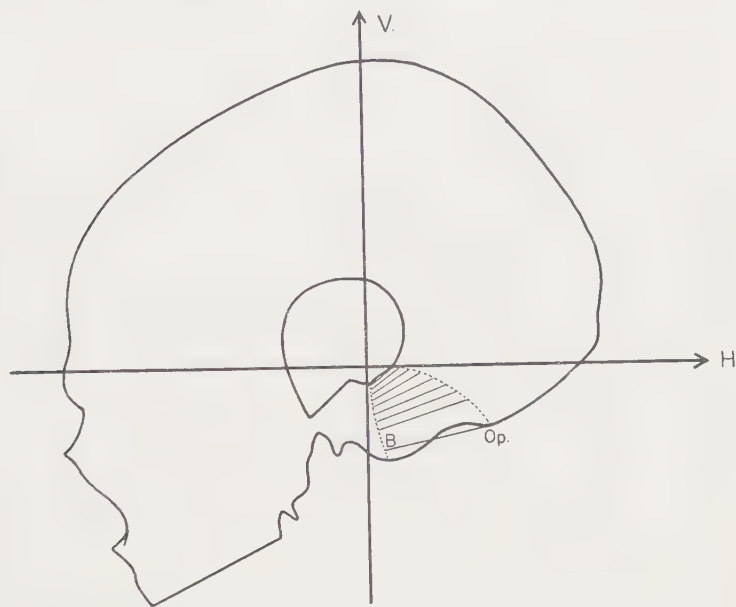


Fig. 7 Sagittal tracings of an early fetal and of an adult skull oriented on the plane of the horizontal semicircular canal (H) and on a vertical (V) erected it, after the method of Fenart ('53). The rotation of the plane of the foramen magnum during growth is clearly shown. Adapted from Fenart ('53).

planes by Kummer, ('52), Ford, ('56), and by Zuckerman, ('55). Postnatal changes constitute about a third of the total rotation and are rapidly completed during the first two years (Bergerhoff and Martin, '54; Bjork, '55). A fuller consideration of the phylogenetic and ontogenetic implications of these rotations is found in Delattre ('52) and in Delattre and Fenart ('56).

Growth of the posterior cerebral fossa is accompanied by morphologic alteration in the occipital bone complex. At birth,

this bone consists of an anterior basioccipital, two lateral exoccipitals and a posterior squamosal element (fig. 8). This latter is roughly divided by the superior nuchal line into an inferior endochondrally derived element (the supraoccipital) and a superior membranously derived element (the interparietal). The superior nuchal line roughly represents the level of attachment of the tentorium cerebelli, which separates the middle and posterior cerebral fossae. Hyaline cartilage

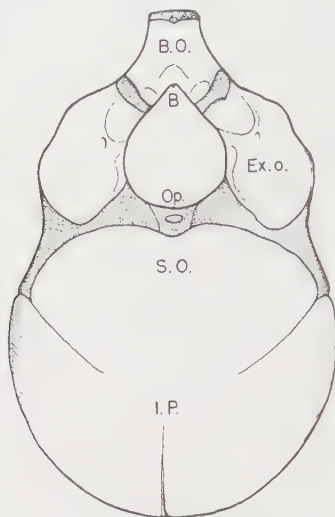


Fig. 8 A basal view of the occipital bone complex in a new born skull. Cartilage is indicated by stippling. (B.O.) basi-occipital; (Ex.O.) ex-occipital; (S.O.) supra-occipital; (I.P.) interparietal; (B) basion; (Op) opisthion. This figure illustrates the unity of the occipital complex. Movement of one portion must entail movement of all of the other portions of the complex.

between the basi- and exoccipitals is reduced to sutural dimensions in the third year with fusion occurring between the fourth and sixth years. The cartilage between exoccipital and squama undergoes an identical sequence in half the time (Augier, '31). The antero-posterior growth of the foramen magnum is very rapid, 77% of the total increase occurring by the second year (Zuckerman, '55).

Our present classification of oblique and vertical occipital deformation confirms the findings of other workers who use such dichotomies as "oblique and erect," "schräg und hoch." It appears that despite the diversity of deforming techniques employed, and despite the conscious intentions of the operators, only these two main types of deformation eventuate. Briefly put, the region of the skull which grows most rapidly while the deforming apparatus is in place, is deformed in a manner which is consistently useful for classification.

Calvarial bones, dura mater and outer periosteum are all derivatives of the embryonic neurocranial capsule, and form a functional whole. In one sense the dura merely represents the unossified portion of this capsule, or conversely, the calvaria is the ossified portion (Deggler, '41). The developing infantile dura mater maintains a continuing relationship to its sites of attachment. All of the layers of the dura are firmly attached to the skull base at only five points. The anterior lateral attachments are at the sharp posterior borders of the lesser wings of the sphenoid; while the posterior lateral attachments are along the crests of the petrous pyramids. The anterior, midline attachment is at the crista galli of the ethmoid. All of the dural layers find their firmest calvarial attachments at the sutural areas (Kokott, '33).

The well organized fiber tracts within the dura which arise from these attachments, such as the falx cerebri, falx cerebelli, and the tentorium cerebelli, have been visualized as playing an important role in the statics and dynamics of the skull (Bluntschli, '25). For our present purposes it is sufficient to note that both intrinsic and extrinsic forces acting on one portion of the neurocranium will be transmitted by the dura mater to all other portions.

Vertical deformation. The direction of the externally applied force is roughly parallel to the plane of the foramen magnum and to the eye-ear plane (fig. 2). The growing neurocranium is unable to expand posteriorly and the intrinsic growth forces seek resolution in other directions. The most obvious clinical alteration, the elevation and lateral expansion

of the neurocranium, does not provide sufficient room for the rapidly growing subtentorial contents of the posterior cerebral fossa. With posterior expansion impossible, there is no alternative except expansion anteriorly. The newly directed force of the expanding cerebellum is directed against the anteriorly situated basioccipital portions of the skull base secondarily producing a basal kyphosis. A similar kyphosis of the brain stem simultaneously occurs (Ariens-Kappers, '47).

The essential equality between the orbital angles of this group and of controls does not imply that no movement occurred. Obviously, if the clivus is kyphosed, there is an equal elevation of the orbital roof. Elevation of the contents of the anterior cerebral fossa permits this osseous elevation to occur. This has been clinically demonstrated in man (Schiffer and Korn, '56) and experimentally in rats (Moss, '58a).

Supratentorial alterations of the vectors of cerebral growth produce changes in dural form. If we regard normal brain form as essentially spherical, the area of the dura mater, by definition, must be minimal in relation to the enclosed volume. Transformation of a volume from a spherical to a non-spherical shape must increase surface area. The overall area of the meninges must increase to meet this newly imposed demand. Alteration of the strongly organized dural fiber tracts (falx cerebri, tentorium cerebelli and falx cerebelli) is apparently accommodated by the upward motion of the anterior lateral and posterior lateral points of basal attachment. The elevation of the anterior points has been discussed immediately above. The upward motion of the petrous crest is a necessary correlate to the similarly directed growth of the immediately adjacent occipital bone complex. The midline attachment, at the crista galli is unaffected, the upward displacement of the posterior end of the falx cerebri being sufficient to provide adequate compensation.

It is important to realize that the vertical relationship of the occipital squama is not produced by the application of the deforming apparatus as such. Deformation is the result

of alteration of the direction of subsequent growth, i.e., deformation is a dynamic rather than a static process.

Oblique deformation. This type of deformation differs from the vertical in that two opposing vectors of external force are applied, roughly parallel to the clival plane (fig. 3). The type of basioccipital deformation produced is diametrically opposed to that found in the vertical type. The increased planum angulation has been termed "platybasia" (Cogan and Barrows, '54; Kahn et al., '55). The present use of this term refers exclusively to a flattening of the clivus. Clinically this term is used interchangeably with "basilar impression" as defining a protrusion of the base of the skull into the posterior cerebral fossa. Parenthetically, in neither type of deformation was a basilar impression produced. Platybasia is a result of the upward and backward movement of the occipital squama produced by the internal growth forces which are redirected by the deforming apparatus. As in vertical deformation, the vectors generated by the growing neural and skeletal tissues are incapable of normal expression. In oblique deformation the vertical increase of the anterior and middle cerebral fossae is inhibited. The resultant expansion, up, back and laterally, represent the only directions still available in which growth may freely occur.

The downward motion of the petrous crest is brought about by the motion, similarly directed, of the occipital bone complex during growth. The mechanism of change in the orbital angle in this type of deformation is similar to that operative in the vertical type. Clival platybasia accounts for only 5° of the total 11° of angular change. The remaining 6° appear well correlated with the upward and backward elevation of the contents of the anterior cerebral fossa.

Clivo-foraminal angle. In both types of deformation the mean clivo-foraminal angle is significantly smaller than normal. The mechanism by which this comes about is quite simple (fig. 9). The occipital bone moves as a unit. Rotation of the clivus, in either direction, is apparently accompanied by a corresponding rotation of the foramen magnum. It is as if

both Basion and Opisthion were rotating about a common center as illustrated in figure 9, in a crudely mechanical model. In vertical deformation basal kyphosis alone is sufficient to account for the diminution of the angle. In oblique deformation the attendant platybasia, as a whole would tend to produce an increase in this angle. Actually the whole occipital squama undergoes a coincident relative upward movement. This is the result of unhindered downward clival growth and relatively hindered downward rotation of the posterior cerebral fossa. This squamosal movement exceeds the platybasic increase and the resultant clivo-foraminal angle decreases.

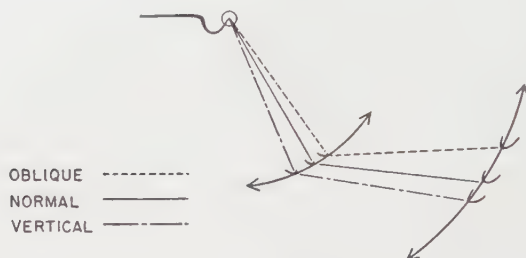


Fig. 9 This figure was constructed using the mean values shown in table 2. The tracings were registered on the planum sphenoidal and on the anterior border of the sella turcica. Note the movement of the plane of the foramen magnum which accompanied both basal kyphosis and platybasia. The arcs of motion of basion and opisthion are shown. Geometrically it appears as if a common center of rotation existed in the posterior clinoid region of the sella.

Postural flattening. In all respects this accidental type of deformation is the functional equivalent of artificial vertical deformation. This clinical condition occurs in a variety of clinical situations; macrocephaly, weakness of cervical musculature, rickets etc., and may also be found in the normal child. In all cases the etiologic factor is prolonged pressure of a bed against the occipital squama. If the child is frequently repositioned in the bed, or when erect cephalic posture is possible, this condition frequently resolves itself spontaneously.

Functional interactions. The neurocranium is a functional matrix consisting of calvarial and basal bones, neural tissues

and meninges. In normal cephalogenesis the rates and vectors of growth of these major functional units are closely coordinated with each other.

The present data offer some insight into the nature of the interaction between the component functional units of the human neurocranium. Redirection of the intrinsic growth vector of one such unit results in alterations in all of the other components. Seemingly, in artificial cranial deformation the sequence is as follows: The external apparatus prevents the immediately subadjacent bone from expressing its own intrinsic growth pattern and from responding to the forces produced by the growing neural tissues. These neural tissues, in turn, are similarly effected and the direction of its growth is altered. Finally the changes in the skull base are brought about as a result of the altered neural growth patterns. Crudely put, the pathogenic sequences work from the outside in.

It follows from this that the entire neurocranium is plastic. No one bone has a *predetermined* topographic position. In vertical deformation, for example, the brain stem and cerebellum are not crushed between a deformed occipital squama and an immovable clivus. Again, the slope of the orbital roof is not determined by the form of the orbital contents alone. Its slope represents of dynamic equilibrium between forces produced by the orbital contents and by forces produced by the overlying frontal cerebral lobes.

Normal human cephalogenesis can be thought of as including the formation of a certain volume of neurocranium. The potential capacity and potential shape of this neurocranial volume are intrinsically determined. As there is good reason to believe that purely mechanical factors can alter the expression of this potential shape in the development of artificial cranial deformation, it is reasonable to assume that analogous mechanical factors similarly determine the attainment of normal skull shape. This hypothesis has recently been exhaustively demonstrated in the chick (Huber, '57). When the imposed extrinsic forces prohibit the attainment of normal

neurocranial shape, it is capable of considerable alteration. Each of the component parts of the neurocranium undergoes a characteristic alteration whose coordination in this pathological situation is as finely adjusted as it is in normal development. That this is so offers support to the belief that the head is far more than just the sum of its component parts; and that normal cephalic growth is more than just the resultant sum of the growth of a number of individual parts.

Finally, it is interesting to note that many human congenital cephalic malformations, premature cranial synostosis for example, present a primary disturbance in the skull base. (Moss, '57b). Analysis of the pathogenesis of these conditions, to be published elsewhere, shows that the sequence of events proceeds in an opposite direction, from inward out, with the same sort of mechanistic interpretation possible.

SUMMARY

1. The lateral skull roentgenograms of 65 artificially deformed American Indian skulls, 54 posturally flattened White American infants and 85 normal skulls were traced to illustrate calvarial form, position of the petrous crest and angulation of the cranial base and of the plane of the foramen magnum.

2. It was found convenient to categorize these deformations into two types, vertical and oblique, depending on the orientation of the occipital squama relative to the facial skull.

3. Artificially deformed Indian skulls, when compared with normal Indian values, revealed the following: (a) in vertical deformation there exists a mid-line basal kyphosis, an elevation of the petrous crest and a ventral shift of the plane of the foramen magnum, (b) in oblique deformation there is mid-line platybasia, a depression of the petrous crest and a dorsal shifting of the foraminal plane.

4. Children with cranial postural flattening, when compared with normal White values, had deformations identical with those found in the vertical type of artificial deformation.

5. A hypothesis is presented which states that cranial deformation is brought about by a redirection of the vectors of normal neurocranial growth. The magnitude of growth of the brain, and therefore of the skull, cannot be altered by extrinsic forces, but its direction can be altered.

6. In support of this view neural and neurocranial growth data are reviewed. A dynamic interpretation of the pathogenesis of cranial deformation is offered.

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RACIAL DIFFERENCES IN HEAT TOLERANCE

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INTRODUCTION

The science of genetics has emphasized the importance of natural selection in the formation of taxonomic races. This in turn indicates the desirability of a re-evaluation of human races in terms of the possible sources of selective forces. Such a re-evaluation may be based on ecological inferences from the distribution of modern races; or specific hypothesis may be tested by experimental means.

It is the purpose of this study, using the experimental approach, to compare the heat stress resistance (heat tolerance) of Negroes and Whites. The development of this type of knowledge will eventually permit us to define some of the role of climate in the selection of certain morphological characteristics.

The American Negro, as a racial group, is certainly a mixed genetic population with considerable White admixture (Herskovits, '28, '30). Some authorities have claimed there is also a high percentage of Indian admixture (Meier, '49), but recent blood studies dispute this claim (Glass and Li, '53). For these reasons it should not be assumed that the heat stress resistance of the American Negro is identical with any other group. Comparison between American Whites and American Negroes has value primarily as an estimate of the variation in resistance which is related to genetic factors. The American Negroes as a group have a genetic inheritance drawn from a tropical population, while American Whites

have lived almost exclusively in temperate climates for many generations. If there is a genetically controlled difference in the heat stress resistance of these groups, it would strongly indicate the presence of a genetic difference in heat tolerance between temperate and tropical populations; however, the extent of the potential genetic difference cannot be ascertained by studying these groups alone.

Past studies on racial differences in heat tolerance are inadequate in light of our present knowledge of acclimatization and human temperature regulation. Most of the comparative work was performed under differing environmental conditions. Caplan and Lindsay ('46) studied Indian mine workers under saturated hot-wet conditions and compared their results to those of Mackworth's ('45) on English Whites. Wyndham studied South African and Tanganyikan Negroes under hot-wet conditions (Wyndham et al., '52 and '53). He compared his results with those obtained on Whites by Eichna et al. ('45), McArdle et al. ('47) and others. He also compared his results with those of Robinson et al. on Mississippi sharecroppers ('41). In both studies a difference between racial groups was claimed. Rectal temperatures and pulse rates were slightly lower in the non-White groups; sweat loss was much lower in the non-Whites.

Two aspects of these studies qualify interpretation of the results. First, the experiments were not designed for direct racial comparisons. Consequently, neither the level of acclimatization nor the climatic exposure conditions were the same for the White and non-White groups. Thus, the comparisons are subject to possible variations in responses caused by the level of acclimatization, small differences in heat stress levels, climatic conditions during non-test periods, and even differences in diet.

Second, in both studies the average body weight of the non-Whites was much lower than the Whites with whom they were compared. From the data of Adolph ('47) relating body weight to sweat loss, it may be assumed that most of the sweat loss difference between groups in the above studies was

a function of the difference in body weight. Of course, even if the group differences in sweat loss were a function of body weight, they could still be considered a genetically determined racial difference since weight is partially under genetic control.

The racial comparison study of Robinson et al. ('41) remains the best study so far, despite the limitations of some of the conclusions reported in the same article. His study was made before acclimitization was a well known phenomenon, and his effort to acclimatize the men brought from the North before comparing them to the Southern Whites was not adequate. However, for a racial comparison, Southern Negro and White sharecroppers were studied. By using groups with similar environmental background, cultural and acclimatization factors were reduced. Fortunately, weights for the two groups were also quite similar. The most important difference noted was in post-stress rectal temperatures. Under identical workloads the Negroes had a mean rectal temperature of 100.9°F as compared to 101.6°F for the Whites. Robinson concluded that the racial differences in heat stress resistance could probably be attributed to racial differences in the surface-area-over-weight index and mechanical efficiency. His second conclusion was based on an assumed racial difference in oxygen consumption per unit of surface area. It has been demonstrated that surface area is not the best reference for oxygen consumption (Wedgewood et al., '53); and it is quite possible that the presumed extra efficiency of the Negro sharecroppers is attributable to a racial difference in body composition.

In summarizing the published evidence it has been possible to find experimental omissions in all the studies, but it cannot be said in any case that the total results have been explained by inadequate experimental or environmental controls. Instead, the published material, particularly Robinson's work, strongly supports the conclusion that there is a genetically determined racial difference in resistance to hot-wet heat stress.

Experiments in heat tolerance

Because of the differences between hot-wet and hot-dry climates, two separate experiments were performed; one under moderate hot-wet conditions in Virginia and the other under hot-dry conditions in the Yuma Desert. The experiments were designed to test whether American White and Negro soldiers showed any difference in their ability to withstand heat stress.

Hot wet conditions

PROCEDURE AND METHODS

Potential strain differences due to racial differences in body size and composition were controlled by selection. One hundred American Negro and 100 American White soldiers were measured at Fort Lee, Virginia. From these 200 men, 40 pairs were matched as closely as possible for per cent of fat in the body, fat-free weight and stature.

These 40 pairs were then subdivided into 4 groups of matched pairs, each of which contained 10 Negro and 10 White soldiers matched for body size and composition. Each group followed the experimental procedure twice and an average of the strain measurements for both days was used for the analysis of the men measured.

Each matched pair was exposed to equal heat stress, and the strain responses of the men were measured. The strain measurements were sweat loss, rectal temperature and pulse rate per minute. In detail, each group reported to a walking course at 12:45 P.M. They stripped and weighed nude on a gram scale accurate to plus or minus 10 grams. They then inserted rectal catheters which contained thermocouples for reading rectal temperatures. All men wore the same style and quantity of clothing which consisted of Army uniforms, caps and boots.

After each pair had weighed and dressed, rectal temperature was recorded on a potentiometer. These temperatures have a reproducibility of plus or minus 1/10 of a degree

Fahrenheit. The men were dispatched in pairs at 5-minute intervals. They walked around a half-mile course at a rate of $3\frac{1}{2}$ miles per hour. To insure that a constant pace was held by all men, two timekeepers were posted, one at the starting point and one at the halfway mark. At the end of one hour the men stopped at the observation tent, where pulse was immediately counted. Rectal temperatures were again read from the potentiometer. Each pair then undressed, wiped off all sweat, and were weighed. Identical procedure was followed for all groups all days.

TABLE 1

A comparison of body composition measurements on matched American Negroes and Whites

MEASUREMENT	WHITE MEAN	N = 40 S.D.	NEGRO MEAN	N = 40 S.D.	MEAN DIFFERENCE
Per cent of fat in the body ¹	5.3	3.2	5.2	3.4	0.1
Fat-free weight (lb) ¹	145.7	13.8	145.7	13.2	0
Stature (cm)	175.1	6.5	172.9	5.7	2.2

¹ Per cent fat and fat-weight were estimated using the QMC caliper described by Newman ('52).

Sweat loss was calculated in the following manner: sweat loss equalled initial weight minus final weight. Water intake and urine output were prevented so that no corrections were required. It was considered unnecessary to correct for respiratory loss of weight since this constitutes a negligible source of error under these conditions (Kleeman et al., '53).

RESULTS

Field work always has one uncontrollable variable: weather. In this study we were unfortunate, since the weather was cool for Virginia in August. Within the test hours the temperature averaged 84.3°F while the relative humidity averaged 44%. As shown in table 2 the low stress level was reflected in low strain levels.

Negro-White differences in heat stress responses are also shown in table 2. As measured by a paired T-test, there was

a significant difference at the 0.05 level or better between the rectal temperatures of the Negroes and Whites both before the walk and afterwards. The difference was increased by the exercise. There was no significant difference at the 0.05 level for pulse rate or sweat loss.

Eighteen Whites, but only 4 Negroes in this study came from Northern States. There was, therefore, the possibility that the difference in rectal temperatures was a function of the Northern origin of the Whites. Eighteen Southern Whites were selected who had been studied on the same days as the Northern Whites and who had comparable body compositions.

TABLE 2
A comparison of American Negro and White heat stress responses

MEASUREMENT	WHITE MEAN	N = 40 S.D.	NEGRO MEAN	N = 40 S.D.	MEAN DIFFER- ENCE	SIGNIFI- CANCE OF DIFFER- ENCE
Pre-test						
rectal temp. (°F)	99.6	0.38	99.4	0.42	0.2	> 0.05
Post-test						
rectal temp. (°F)	100.4	0.45	100.0	0.45	0.4	> 0.01
Pulse rate						
(beats per/min)	122.4	12.9	119.4	14.6	3.0	< 0.05
Sweat loss						
(gm per/hr)	912	139	873	137	39	< 0.05

The strain measurements of these 18 Southern Whites were compared to the same strain measurements for the Northern Whites. The slight differences that were found indicated the Southern Whites were lower in heat tolerance. However, these differences were in no case statistically significant and were probably a function of the size of the sample. This comparison seemed to indicate that the locale from which the subjects were drawn did not influence their heat tolerance.

There still remain several possible non-genetic explanations for the difference between the racial groups. Probably some

differences exist in the childhood nutritional patterns of the two groups. However, body composition was controlled by selection, and differences in responses cannot be attributed to the Negro's lower fat or greater linearity.

Differences in physical conditioning might also effect resistance (Bass et al., '55). For this reason an effort was made to obtain racial groups in the same state of physical training. The men participating in this study came from the same Army units, and as the Army no longer separates Negro and White troops, these men had, for at least the last 6 months, performed similar duties.

There may be other potential sources of difference which have not been considered, but the data strongly suggest that under similar mild wet heat stress loads American Negroes have lower rectal temperatures than American Whites and that this difference is probably not attributable to post-conception environment. The data do not indicate the nature of the genetic difference. That is, it cannot be determined whether the lower rectal temperatures in the Negroes are related to greater cardiovascular output (which would increase internal to peripheral heat flow), greater mechanical efficiency, or more effective performance in other temperature regulatory mechanisms such as sweat salinity or distribution.

Because the Negroes and Whites in this study were selected for similar gross morphologies, neither group is necessarily representative of its respective population in terms of body composition. From studies of Army populations it is known that U. S. Army Negroes have body compositions considerably different from Whites (R. Newman, '56). The American Negro population is lower in body fat and has slightly more fat-free weight. If representative samples had been chosen the results would probably have reflected greater racial differences in heat strain measurements. On the basis of work in previous experiments on White soldiers (Baker, '55), a fatter group would have had higher rectal temperature, pulse rates and sweat losses. Thus, in typical samples not matched for body composition, the Negro-White differences in strain

responses would have been greater. However, it cannot be concluded that the relationship found for Whites (between gross morphological characteristics and heat strain indicators) hold for Negroes.

The differing daily weather conditions made it necessary to analyze each daily subsample of Negroes and Whites separately. The multiple subdivision of the group left a maximum sample size of 10, which was small for correction analysis. Rectal temperatures were significantly correlated with fat in only one of the subsamples. This is to be expected because of the low stress level. As shown in table 3, there was consistent and significant correlation between sweat loss and fat-free weight for both Negroes and Whites.

TABLE 3
Correlation coefficients for sweat loss and fat-free weight

SAMPLE GROUP	WHITES		NEGROES	
	N	Correlation Coefficient	N	Correlation Coefficient
August 4 and 5	10	0.64	10	0.51
August 6 and 9	10	0.94	10	0.60
August 10 and 11	10	0.58	10	0.86
August 12 and 13	10	0.66	10	0.71

The regression equations of sweat loss on fat-free weight indicated a considerable between-group variation in regression slopes. Most of this variation is attributable to the small sample sizes, but some part of it may be related to the between-group differences in heat stress levels.

While weather conditions may have affected the regression slopes, no significant differences were found between the regressions of sweat loss on weight for Negroes and Whites. These results make it more probable that the regressions of fat-free weight on sweat loss found for Whites may be validly applied to American Negroes. Assuming that there is no difference in the regressions, in representative racial samples, there would not only be a significant difference in rectal

temperature which may under heat stress be genetically determined but also a significant difference in sweat loss, determined by racial differences in body composition.

Hot dry conditions

PROCEDURE AND METHODS

For the study under desert conditions a sample of 8 White and 8 Negro subjects was chosen from a group of approximately 50 men. These two samples were matched for body composition and proportions as the group for hot wet conditions had been matched.

Measurements were also made of skin color reflectance on both groups. A Photovolt reflectometer was used to make the measurements. The readings with an amber tristimulus filter were made weekly at 5 sites; the cheek, the chest over the nipple, the inner arm, the outer arm, and the back over the inferior angle of the scapula. The measurements were repeated three times at each site, and an average was calculated.

After thorough heat acclimatization in the desert, a Latin square experimental design was implemented so that each man was studied under 8 different desert conditions for 2 hours. Negroes and Whites were paired so that in each day's study there were 8 pairs, one under each condition. Each man repeated each condition 4 times for a total of 32 exposures. The conditions were combinations of: sun, shade, nude, clothed, walking and resting. Shade was obtained from a large assembly tent. Walking was around a small rectangular course at the rate of three miles per hour, and rest was sitting inactive on a foot locker. A more complete description of the experimental design and conditions will be published in a forthcoming Quartermaster Research and Development Technical Report.

The physiological measurements made were: rectal temperature (initial and final) — by means of a clinical thermometer; total sweat loss — by weight change corrected for water intake; evaporated sweat loss — by total sweat loss minus

sweat retention in the clothing; pulse rates — counted for 20 seconds at the wrist.

RESULTS

Analysis of the effects of the experimental variables showed that most conditions had significantly different effects on the men. The Negroes and Whites showed significant differences (by variance analysis) in their initial and final rectal temperatures but not in total sweat loss, evaporated sweat loss or pulse rates. Table 4 shows the absolute values and the difference in rectal temperature between Negroes and Whites.

The Negro-White difference in initial rectal temperature is, of course, in no way affected by the condition to which they were later exposed but is important in calculating the total heat storage during the experimental condition. Prior to the experiment, the men rested on cots for one hour in their tents in the desert. The racial difference found in the initial rectal temperatures must, therefore, be attributed to this condition as there is no difference under neutral climatic conditions (unpublished data).

The final rectal temperature differences seem to show a very definite pattern related to the condition to which the men were exposed. When the men were in the shade or protected from the direct sun by clothing, the Negroes had a slightly higher rectal temperature than the Whites. However, when the nude skin was exposed to the sun the differences between the groups increased so that when walking nude in the sun, with a maximum of skin exposed, the difference amounted to almost four-tenths of a degree Fahrenheit. This pattern is exposed even more clearly when the rectal temperature rise from initial to final is examined.

When the Negroes were protected from the sun, their rise in rectal temperature was the same or even lower than that of the Whites. Only when the two groups were walking nude in the sun did the Negro rectal temperature rise substantially more than the White.

TABLE 4
Rectal temperature for Negroes and Whites

TEMPERATURE DEGREES F.	CONDITIONS						
	Shade Clothed Rest	Shade Nude Rest	Sun Clothed Rest	Sun Nude Rest	Shade Clothed Walk	Sun Clothed Walk	Sun Nude Walk
Initial							
Negroes	99.19	99.21	99.21	99.21	99.27	99.23	99.22
Whites	99.00	99.02	99.01	99.00	99.02	98.96	99.08
Difference	- 0.19	- 0.19	- 0.20	- 0.21	- 0.25	- 0.27	- 0.13
Final							
Negroes	99.19	99.26	99.32	99.54	100.15	100.31	100.40
Whites	99.11	99.18	99.30	99.30	99.92	100.07	100.02
Difference	- 0.08	- 0.08	- 0.02	- 0.24	- 0.23	- 0.24	- 0.38

TABLE 5
Rectal temperature rise from initial to final readings

	CONDITION							
	Shade Clothed Rest	Shade Nude Rest	Sun Clothed Rest	Sun Nude Rest	Shade Clothed Walk	Shade Nude Walk	Sun Clothed Walk	Sun Nude Walk
Negroes	0.00	0.05	0.11	0.33	0.88	0.97	1.09	1.20
Whites	0.11	0.16	0.29	0.30	0.90	0.99	1.11	0.94
Difference	+ 0.11	+ 0.11	+ 0.18	— 0.03	+ 0.02	+ 0.02	+ 0.02	— 0.26

Although the sweat losses were not significantly different between the two groups, at the 0.05 level, the differences reflect very closely what was found in rectal temperatures.

Again the major difference is found when the two groups are exposed nude to the sun although a fairly large difference also appears when the two groups are walking clothed in the shade.

The effect of the *nude* exposure in establishing racial difference in responses, very strongly suggests that greater heat absorption by the Negro skin may be the major factor determining the observed differences. By utilizing the skin reflectance reading an estimate was made of the difference between the two groups. The amber tristimulus filter used to measure skin color transmits light in the approximate wavelength of 600 millimicrons, which falls near the middle of the visible sunlight spectrum, thus, skin reflectance reading with this filter offers a rough estimate of the heat absorption from the sun. From the 4 areas exposed to the sun (cheek, chest, arm and back) an average reflectance during the study was derived. It was found that the Negroes absorbed approximately 84.6% of the light received while the Whites absorbed approximately 69.7%.

The average radiation of the sun was measured with a pyroheliometer in a horizontal position. For the total experimental period the radiation averaged 846.5 kilogram Calories per square meter per hour (kg Cal. per m² per hour). If this is corrected for the normal incidence, then the radiation intensity was 977.5 kg Cal. per m² per hour. Woodcock (manuscript) has shown that at the angle of the sun encountered under these conditions the seated and walking man has about 20% of his surface area exposed to the sun. The Negroes and Whites had identical surface areas of 1.90 square meters as calculated by the DuBois formula from height and weight (DuBois, '36). This means they both had about 0.38 square meters of skin exposed to the sun. From these figures we

TABLE 6
Total sweat losses for Negroes and Whites

	CONDITION					
	Shade Clothed Rest	Shade Nude Rest	Sun Clothed Rest	Sun Nude Rest	Shade Clothed Walk	Sun Clothed Walk
	<i>Sweat loss in grams</i>					
Negroes	963	1255	1393	2010	2143	2582
Whites	961	1219	1407	1857	1997	2502
Difference	-2	-36	+14	-153	-146	-80
						2796
						2656
						-140

TABLE 7
Evaporated sweat loss for Negroes and Whites

	CONDITION					
	Shade Clothed Rest	Shade Nude Rest	Sun Clothed Rest	Sun Nude Rest	Shade Clothed Walk	Sun Clothed Walk
	<i>Sweat loss in grams</i>					
Negroes	922	1229	1326	1982	1953	2350
Whites	923	1195	1344	1823	1822	2286
Difference	+1	-34	+18	-159	-131	-64
						2780
						2608
						-172

calculated the approximate heat absorbed from the sun by the two groups by means of the following formula:

$$\text{Kg. Cal. of heat absorption} = (\text{Two-hour radiation in kg Cal. per m}^2) \\ \times \text{surface area exposed} \times \text{skin absorption}$$

It was found that the Negroes absorbed 628 kg Cal. during the average two-hour exposure while the Whites absorbed only 518 kg Cal. or a difference of 110 kg Cal.

Although rectal temperatures were significantly different for the two racial groups, the total heat storage difference was very small. This means that there should have been a fairly large difference in evaporated sweat loss to account for a large difference in solar radiant energy absorption. Assuming water evaporation to have an equivalent of 0.58 kg Cal. per gm, the Negro theoretically should have evaporated 190 more grams of sweat than the White. As shown in table 7 the difference was not this great.

If these theoretical calculations are nearly correct, then it must be assumed that in some manner the Negro was able to dissipate more heat than the White without proportionately greater sweat loss.

The greater solar radiation absorption of the Negro is primarily a function of the melanin deposited in the epidermis and most of the solar energy is presumably converted to heat in this surface layer. The assumption is supported by the work of Laurens and Foster ('36) who showed that at 6 mm depth Negro and White skins had the same temperature when exposed to visible infra-red radiation. If the additional Negro radiation absorption is converted to heat in the epidermis, the Negro's exposed skin must have a higher temperature. This in return means that during this test, where the ambient temperature was higher than skin temperature, less long wave radiant heat was received. As skin temperature was not recorded during this study, the hypothesis cannot be checked, however, it forms a very logical explanation for the discrepancy between expected and found heat losses. It would mean that when Negro and White skin is exposed to solar radiation, although the Negro skin ab-

sorbs more of this energy, it warms more on the surface and thus loses more long wave radiation to an environment which has a temperature below that of the skin and gains less from an environment above skin temperature.

DISCUSSION AND CONCLUSIONS

Until recently the human species was taxonomically divided into races based on what were assumed to be adaptively "neutral" characteristics. At first these were body measurements and attributes, later blood factors such as the ABO antigens. In turn each of these characteristics was proven to have selective or adaptive aspects so that they could no longer be considered "neutral." This has led the modern geneticist and physical anthropologist to postulate a system of races which is based on geographical population isolates which conform more closely to genetic units (Boyd, '53; Garn and Coon, '55). Classification of this nature certainly is genetically sound since it fulfills most of the requirements for the group to be considered a breeding isolate. The most important criticism which can be leveled against the geographical concept of race is that it is only a functional system without time depth or proof of genetic affinity. This is not so much a criticism of the system as it is a comment on the present state of our knowledge about the genetic and adaptive aspects of human morphology. Even though the geographical system appears to be the best that can be formulated at this time, we should not be satisfied with it. Instead, as pointed out by Garn ('57), we must seek to define the adaptive nature of morphological characteristics.

Until the mass population shifts of the late eighteenth and early nineteenth centuries, African and European populations were restricted to separate climatic zones. Evolutionary theory suggests that some of the morphological differences that separate these groups may be based on the selective survival of genes which were adaptive to these differing environments. However, climatic zones vary in many ways and surveys of the native populations do not tell us which en-

vironmental isolates have exerted selective pressure on the morphological characteristics. One of the best documented factors in the environment is climate; given this single factor, it has been possible to apply an experimental approach and thus investigate the relative tolerance of two racial groups to a given environmental stress.

In the present studies the experimental approach has been applied to investigate the possible role of climate in creating the differences in American Negroes and Whites. The results of these experiments fit the spatial distribution of present day populations, since the Negroes of the world do not predominate in desert areas but are found in hot-wet areas. Distinctive groups such as Nilotics, Bushmen and Australian aborigines are the only Negro-like men found in the desert. These groups have been variously described as race mixtures, hybrids and even separate races. While any of these descriptions is a possibility, the experimental evidence indicates the morphologically typical Negro would be selected against by the climatic conditions, and the alternative possibility, therefore, remains that these groups came from the same ancestral genetic pool as the hot-wet area Negro, but were modified by climatic selection.

Once quantitative relationships have been established between environmental elements, (e.g., air temperature, solar radiation) and racial characteristics, it should be possible to apply these relationships to data on previous climates. In this way critical attention can be focused on those areas and times at which climate was exerting strong adaptive pressure. This will permit us to construct a racial classification with time depth as well as inferred genetic unity.

SUMMARY

The physiological responses of American White and Negro soldiers were studied under hot-wet and hot-dry conditions.

Under hot-wet conditions 40 pairs of men matched for body fat, weight and stature were walked around a course at $3\frac{1}{2}$ mph for one hour.

Under hot-dry conditions 8 pairs of men also matched for body fat, weight and stature were studied under 8 different conditions which included combinations of clothing, sun, shade, walking and sitting.

The results of this series of experiments indicated:

1. Under hot-wet conditions with both Negroes and Whites clothed and walking, the Negroes had a higher physiological tolerance.

2. Under hot-dry conditions with both groups clothed, walking, or sitting they had about equal tolerance.

3. Under hot-dry conditions with both groups nude and exposed to the sun, sun-tanned Whites had the higher tolerance.

These results further suggested that the differences found were not a function of transient environmental effects and may be mostly genetic in origin. The results are discussed in relation to racial taxonomy systems and the distribution of human morphological attributes.

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FREQUENCY OF BLOOD GROUP ANTIGENS IN THE DESCENDANTS OF GUAYQUERÍ INDIANS

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ONE FIGURE

Margarita is an island situated some 20 miles off the North-eastern coast of South America. Politically, it belongs to the Republic of Venezuela.

The aboriginal population of the island of Margarita was an Indian group known by the name of Guayquerí. Discovered for Spain in 1499 or 1500, the Guayquerí have been in close contact with Europeans for 460 years. In 1509, settlers from Spain established a royal colony on Cubagua to exploit the rich pearl beds of the islands Margarita, Coche and Cubagua. The Guayquerí, however, refused to assist in the frantic exploitation activities, so that the Spaniards had to import Lucayan Indians from the Bahamas and Indians from the South American mainland, as slaves, to increase the production.

In general, the attitude of the Guayquerí towards the Spaniards had been expressedly friendly, and in public acts the Spanish King used to call them his "dear, noble, and loyal Guayquerí." For this same reason, the Guayquerí enjoyed several privileges and the alliance between the Europeans and the Margarita Indians appears to have been established on equal terms soon after the foundation of Nueva Cadiz, the Spanish settlement on Cubagua. Intermarriage between Europeans and the Indians started early. In 1524 the Spaniards were allowed by the Guayquerí to settle on the main island, Margarita, and at about that time a Spaniard of ele-

vated birth, Don Diego Fajardo, married an Indian woman-chieftain, known as Doña Isabel. Consanguineal kin ties connected this Indian lady with people of the Venezuelan coast.

Starting in 1555, the half Guayquerí, Francisco Fajardo, son of Doña Isabel and Diego Fajardo, undertook several expeditions to explore or conquer the Caracas region, leading Guayquerí and Spaniards into battle against Carib Indians and other tribes. Because of these voyages Guayquerí were left behind on the mainland and emigrated along the Orinoco and some of its tributaries. A larger settlement of Guayquerí was also established at Cumana in 1678, where the Indians lived among the Spaniards on the coast in friendly manner, while keeping in close contact with their relatives on the island (McCorkle, '52).

The ethnic affiliation of the Guayquerí has been a problem ever since critical studies of the American Indian began.

Historical records are contradictory. In 1525 Marcelo de Villalobos (Herrera y Tordesillas, 1730) described the natives of Margarita as Caribs, but this statement was obviously a pretext to enslave the Guayquerí. Herrera y Tordesillas (1730) writes that in 1520 the natives of the island were especially described as being not Carib.

Linguistics can not render any bigger assistance either. Guayquerían is extinct and the respective indications dispersed throughout literature are not conclusive. Humboldt ('41) was told by old people (Guayquerí) that "their forefather's" language was a dialect of the Warrau language of the Orinoco Delta. Similar information was forwarded by Codazzi ('40), and Wilbert ('57) tried to demonstrate Warrauan elements existing together with Cariban and Arawakan in the vocabulary of so-called "Indian words" he collected among the descendants of the Guayquerí on Margarita. Sanchez ('21), Krickeberg ('45), and Rivet ('24) assigned the language of the Guayquerí to the Carib linguistic family. Acosta Saignes ('54) may be right in saying that Krickeberg and Rivet base their statement on Gilij's (1791) expert opinion. In the absence of any vocabulary, however, a more

definite statement in this respect is not to be expected from linguistics (McCorkle, '54).

As to the somatology of the Guayquerí, Humboldt ('41) distinguished them from the tubby Chaima and Caribs of Cumana and from their nearest 19th century mainland neighbors. Dalton ('12) refers to the "strangely Mongolian appearance" of the descendants of the ancient Guayquerí on Margarita, and Federmann ('45) describes his 600 "Indios Guaycaries" as people with a skin as "black as coal." Both the latter traits would fit more the Warrau than the Carib.

Today, there still exist some villages of the descendants of the Guayquerí on Margarita Island. Because of their historical tradition it is safe to say that these Indians have blood admixture with other Indians on one hand, and with Europeans and Negroes on the other. Negro blood was brought in by the slaves from West Africa.

By means of blood group antigen testing, we endeavored to contribute to a certain extent towards the ethnic identification of the Guayquerí and the results of this study, as presented in the present paper, lend themselves to some interesting discussions.

Blood group antigen tests

The blood group studies were performed in Fajardo, a village of Guayquerí descendants. Most of the individuals exhibited an Indian strain in them, but White and Negro traits were also present.

Blood was taken from 103 unrelated adult individuals. It was tested for A₁A₂BO, MN, Rh, Duffy and Diego blood group systems. To furnish some comparative data, the incidence of the same blood groups of two Carib and of two Warrau populations is included (table 1). Paper electrophoresis studies of the hemoglobin of the Guayquerí blood were performed also, using a pH 8.6 barbital buffer.

The blood samples showed a relatively high incidence of A₁, A₂ and B which makes it quite certain that extensive interbreeding with Caucasoids and Negroids has taken place. The

TABLE 1

Frequency of A_1A_2BO , MN, Rh, Duffy and Diego blood group systems in the population of Fajardo, two Warrau and two Carib sub-tribes

	FAJARDO	GUAYO ² WARRAU	WINIKINA ¹ WARRAU	CARIB ³ RIO NEGRO	CARIB ³ ANZOATEGUI
NUMBER TESTED	103	81	72	125	170
A_1A_2BO system					
Phenotypes (%)					
A_1	28.15	0	0	0	0.58
A_2	6.79	0	0	0	0
B	10.67	0	0	0	0
A_1B	2.91	0	0	0	0
O	51.45	100	100	100	99.4
Genes (%)					
P_1	16.65	0	0	0	0.29
P_2	4.59	0	0	0	0
q	7.25	0	0	0	0
r	71.72	100	100	100	99.7
MN system					
Phenotypes (%)					
M	38.83	28.39	15.27	32	—
MN	44.66	44.44	43.05	52.80	—
N	16.50	27.16	41.46	15.20	—
Genes (%)					
M	60.87	50.61	36.79	58.40	—
N	38.83	49.38	63.18	41.40	—
Duffy system					
Phenotypes (%)					
Fy (a +)	70.87	91.35	97.22	—	—
Fy (a —)	29.13	8.64	2.77	—	—
Genes (%)					
Fy ^a	45.93	70.61	83.36	—	—
Fy ^b	54.07	29.39	16.64	—	—
Rh system					
Phenotypes (%)					
CCDE	1.94	2.41	11.11	7.20	Rho(D) 100%
CCDee	19.41	45.67	44.41	62.40	
ccdee	7.76	0	0	0	
CeDE	20.38	45.67	38.88	14.40	
CeDee	22.33	3.70	2.77	12.80	
ceDE	20.38	2.46	2.77	3.20	
ceDee	7.76	0	0	0	
Chromosomes (%)					
CDE	1.57	1.79	7.89	4.44	—
CDe	44.53	67.58	66.62	78.99	—
cde	27.84	0	0	0	—
cDE	14.51	30.63	25.49	16.57	—
cDe	11.55	0	0	0	—
Diego system					
Phenotypes (%)					
Di (a +)	12.62	3.69	0	24.80	29.41
Di (a —)	87.37	96.31	100	75.20	70.58
Genes (%)					
Di ^a	6.53	1.9	0	13.50	16
Di ^b	93.47	98.1	100	86.50	84

¹ Layrisse, Arends and Wilbert, '58.² Nuñez Montiel and Nuñez Montiel, '57.³ Layrisse, Arends and Dominquez Sisco, '55.

frequency of the gene Fy^a expressed a middle average between the high incidence generally found in Indians (Mourant, '54), the low incidence in Spaniards, and the still lower one in Negroes. With respect to the Rh system, the frequency of the chromosome Ro (cDe) (11.5%), is indicative of Negro admixture, since neither the Carib nor the Warrau carry this chromosome and since its frequency in Spaniards, in spite of being higher than in other European peoples, is no more than 5%.

With exception of the Warrau, who have shown a low frequency of the gene M (Layrisse, Arends and Wilbert, '58), most of the South American Indians exhibit a gene M frequency of more than 70% (Mourant, '54). Thus, the high incidence of the gene M (61%) in the population of Fajardo is indicative of a strong Indian component.

The Diego antigen frequency was 12%, a frequency which appears to be very high for a hybrid population. We shall discuss this finding later on in more detail.

Rate of admixture

Since we have to consider the population of Fajardo as being the result of an admixture of three base populations, the application of the incidence of blood group antigens, in order to determine the rate of interbreeding of each base population, represents some greater difficulties; especially because of the necessity of employing blood group genes or chromosomes which are of a high frequency in one base population, lower in the other, and absent in the third one. Applying Bernstein's formula ('31), only the Di^a , A, r (cde) and Ro (cDe) were selected, in order to determine the race admixture (table 2). The formula is expressed as follows:

$$\text{Percentage of gene admixture} = \frac{q_x - Q}{q - Q} \times 100$$

Q and q are the gene frequencies in the base population and q_x is that of the hybrid population.

For the determination of Spanish admixture, the chromosome r (cde) and the gene A, present in a high incidence in

Spaniards, in a low incidence in Negroes and absent in some Indian stocks (Carib and Warrau), were chosen. The chromosome cde has shown a frequency of about 37% in Spaniards, and of 20% in West African Negroes, while the gene A has a frequency of 29% in Spaniards and 15% in West African Negroes. Employing the gene A, the percentage of Spanish admixture in Fajardo was calculated to be 44.57%. By employing the chromosome cde, the admixture is estimated to be 46.11%.

TABLE 2

Rate of Spanish, West African Negro and Carib Indian admixture found in the population of Fajardo; according to Bernstein's formula

	GENES OR CHROMO- SOMES	Q	q	qx	PERCENTAGE OF ADMIXTURE
Spaniards	A	15	29	21.24	44.57
	r (cde)	20	37	27.84	46.11
West African Negroes	Ro (cDe)	5.26	55	11.55	12.64
Carib (Cariña) Indians	Di ^a	0	16	6.5	40.6

The chromosome Ro (cDe) is considered the best for calculation of the Negro gene flow in a hybrid population, since it is present in about 55% of African Negroes and in less than 5% of Caucasoids. Its incidence in Carib and Warrau Indians tested, permits us to use this chromosome for the determination of Negro admixture in the population of Fajardo, which amounts to 12.64%. This feature is in agreement with the presence of only one case of the abnormal hemoglobin of the type 'AS.

The figures for the average incidence of A₁, r and Ro were taken from the incidences of various populations of Spain (Miserachs-Rigalt, '49; Race et al., '49; Grifols-Lucas and Manao, '52; Guasch et al., '52), since, hypothetically, we suppose that the immigrants came to Margarita Island in equal numbers from the various provinces of Spain, and started to

interbreed with the Guayquerí Indians. With respect to the same genes and chromosomes in Negroes, we took an average of their incidence in the West African Negroes (Mourant, '54).

Since the Di^a must be considered as being negative in Caucasoids and in West African Negroes (Layrisse and Arends, '57a, '57b; Layrisse, '58), the rate of Indian admixture in Fajardo can be calculated by knowing the Di^a frequency of the base Indian population which has entered in the formation of this hybrid community. The affiliation of the Guayquerí with the Warrau is practically impossible (Layrisse, Arends and

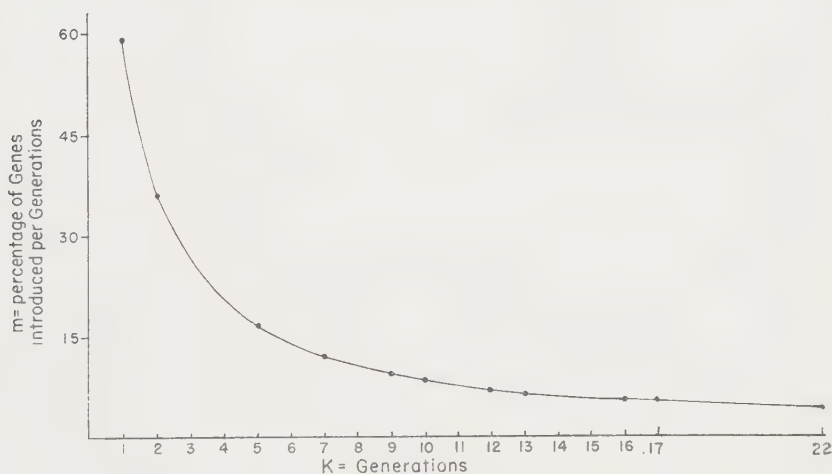


Fig. 1 The White plus Negro gene flow per generation into the Guayquerí Indians, according to the incidence of Di^a in the population of Fajardo.

Wilbert, '58) considering the high Diego positive incidence of the Fajardo sample. The affiliation of the latter with the Carib, however, would seem to fit very well, since calculating the admixture of Spaniard plus Negro, a result of about 60% was achieved, while the calculation of the Indian admixture by taking the Carib as a base population, resulted in 40%. The possibility that the Warrau as well as the Carib might have contributed to the formation of the population of Fajardo can be ruled out because it would increase the incidence of O and $Rh_o(D)$ to a level very much higher than that observed in the course of our studies.

According to the data presented above, the actual population of Fajardo has been formed by the interbreeding of about 40% of Carib Indians, 45% of Spaniards, and 12% of Negroes; however, this figure should be taken as approximate owing to the relatively small number of individuals tested.

As stated by Stevens ('52) and Glass and Li ('53), Bernstein's formula refers only to the accumulative intermixture which has occurred in a population over a period of time, but it tells nothing about the dynamic process of intermixture, because it assumes its occurrence in but one single gene-ratio. Thus, applying the formula of Glass and Li ('53) which expresses the dynamics of racial intermixture in a population, the White plus Negro gene flow into Guayquerí has been calculated from the beginning of their interbreeding until today. This formula is expressed as follows:

$$(1 - m)^k = \frac{q_k - Q}{q_0 - Q}$$

where k is the number of generations of intermixture, m the percentage of genes in hybrid population which is introduced per generation from White plus Negro bas populations, q_k is the Di^a gene frequency in Fajardo, q_0 the Di^a gene frequency of Anzoategui Caribs who are living very close to Margarita Island, and Q , the Di^a gene frequency in Spaniards plus West African Negroes.

The date of the beginning of interbreeding of Whites and Negroes with the Guayquerí cannot be determined accurately. According to the tradition, interbreeding of Whites with Guayquerí started at about 1500, while any appreciable intermixture began only towards the end of the 16th century. The Negroes arrived here at about the same time, so that the year of 1600 appears to be a fair date to be taken into consideration for the beginning of intermixture.

According to Venezuelan Official Statistics (Ministerio de Sanidad), the average age of mothers from Caracas giving birth to their first child is 26.49 years, and that of the fathers at the birth of their first child, 31.48. In Porlamar, a town situated in the vicinity of Fajardo, the average age is 26.62

for the mothers and 32.68 for the fathers. The respective data for Fajardo are not available. Taking into consideration the custom of the Venezuelan Indians to marry rather soon after the girls have passed their first menstruation, we consider for the sake of the present paper the average length of a generation to be somewhere between 16 and 29 years, or roughly, within the neighborhood of 20 years.

Figure 1 shows the various data for m in the function of generations. If we take the year of 1600 as the beginning of intermixture in Fajardo while determining the length of generation with 16.20 and 29 years, only small differences for the values of m will be obtained. With a generation period of 16 years, 22 generations have occurred in Fajardo between 1600 and 1950, so that the Negro plus White gene flow per generation amounts to 4%. With a generation period of 20 years, 17 generations passed by, and m would be 5.2%. Even with a generation period of 29 years, that is after 12 generations, the value for m will only rise to 7.2%.

A similar estimation of gene flow per generation from one population into another was first reported by Glass and Li ('53) who found 3.5% of gene flow per generation from the U.S. White population into the Negro population, while it reached a percentage of 30.5 after 10 generations occurring between 1675 and 1950. Roberts ('55) using blood group frequencies in various tribes of West African Negroes, recalculated the gene flow per generation from the American White population into the American Negro population, finding it to be somewhere between 0.2 and 2.5%, while the amount of accumulated White admixture was of about 20% after 10 generations.

Saldanha in Brazil ('57), comparing the incidence of blood group antigens in Negroes from Bahia, Sao Paulo, and Rio de Janeiro, with the African Negroes, obtained values of 4.5-5.0% of a gene flow per generation from Whites into the Brazilian Negro population, which amounts to 40% after 12 generations.

Final comments

Returning to the discussion of the problem concerning the ethnic identification of the Guayquerí, the divergent statements assigning the Warrau and the Caribs as the possible people with whom the Guayquerí could be affiliated, have to be remembered. Judging from the results obtained among Venezuelan Indians tested for the Di^a antigen, an affiliation of the Guayquerí with the Warrau appears to be impossible (table 1). While considering the high frequency of 12% Di^a in the tested hybrid population, the affiliation of the former with the Caribs suggests itself.

As we learn from Caribbean ethnology and archeology, the Arawak migrated in pre-colombian times from the South American mainland across the islands of the West Indies as far north as Cuba. Therefore, a possible affiliation of the Guayquerí with this people should at least be taken into consideration. Again, judging from the incidence of Di^a, such a genetic connection between the two peoples seems to be ruled out by the fact that according to the data available, the frequency of Di^a in almost pure Arawak (Goajiro) is only 5.2% (Layrisse, Arends and Dominguez Sisco, '55).

There appears to exist no doubt as to the identification of the population of Fajardo with the descendants of the Guayquerí, so that the sample studied may be taken as representative for the rest of the Guayquerí population of Margarita. According to the result of the investigation, the Guayquerí seem to have had genetic affiliations with those representatives of Venezuelan Indians who also have a high Di^a frequency and who ethnolinguistically have been identified as Carib.

SUMMARY

The blood group testing of 103 unrelated adult individuals from one of the modern Guayquerí villages, Fajardo, reveals that they have an admixture of approximately 45% of Spaniard, 12% of Negro and 40% of Indian. According to the incidence of Diego antigen which amounts to 12%, it was possible

to demonstrate that the 40% of Indian blood in that admixture is of Carib origin.

The dynamic process of intermixture was calculated by employing the formula of Glass and Li. The White plus Negro gene flow per generation into the Guayquerí Indians was shown to have been about 5.2%, while the amount of accumulated White plus Negro admixture was about 59.4% after 350 years.

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THE CRANIAL BASE

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SIX FIGURES

INTRODUCTION

The midline cranial base, extending from the anterior edge of the foramen magnum (basion) to the fronto-nasal suture (nasion), is one of the most important regions of the skull from the point of view of anthropological studies, while in its growth it affects both the cranial and facial regions of the skull. It is proposed in this paper to collect together data from various sources and discuss its development, its growth, and its morphological and phylogenetic significance.

The parts of the cranial base

In the human adult the cranial base consists of the following elements from behind forwards (fig. 1):

- (a) The basal part of the occipital bone.
- (b) The spheno-occipital synchondrosis. This persists until about 17–20 years of age.
- (c) The body of the sphenoid bone.
- (d) The spheno-ethmoidal suture. This is continuous laterally with the fronto-sphenoidal sutures on the floor of the anterior cranial fossa.
- (e) The cribriform plate region of the ethmoid bone uniting the midline mesethmoid (perpendicular plate and crista galli) with the bilateral facial parts of the ethmoid.
- (f) The fronto-ethmoidal suture and the foramen caecum.
- (g) The frontal bone (glabella region).

The structure of the cranial base in the anthropoid apes is the same as in man, but in the monkeys, lower primates and other animals a second synchondrosis, situated between the presphenoid and postsphenoid elements of the body of the sphenoid, persists until after the eruption of the second permanent molars. Its significance will be discussed later.

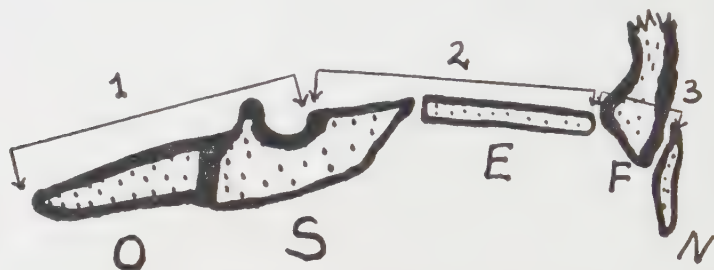


Fig. 1 Human mid-line cranial base. O, basioccipital; S, sphenoid; E, ethmoid; F, frontal; N, nasal; 1, posterior cranial segment; 2, middle cranial segment; 3, anterior cranial segment.

In order to study the growth of the cranial base it can best be divided into three segments. These are (fig. 1):

1. From basion to pituitary point (the posterior segment).
2. Pituitary point to foramen caecum (the middle segment).
3. Foramen caecum to nasion (the anterior segment).

In the majority of studies on the cranial base (2) and (3) together make up the anterior segment.

The development of the cranial base

The cranial base from the foramen magnum to the region of the foramen caecum is pre-formed in cartilage which is continuous with the cartilage of the nasal capsule, the latter including the cartilage of the nasal septum (fig. 2). The frontal bone develops in membrane above and slightly in front of the anterior end of this great mass of cartilaginous tissue extending from the foramen magnum to the front end of the nasal septum. In this mass of cartilage centers of ossification appear from behind forwards in the following order (Frazer, '40):

1. A single center for the basioccipital about the middle of the third month of fetal life.
2. Two to four centers for the postphenoid about the end of the 4th month of fetal life.
3. Two centers for the presphenoid during the 4-5th months of fetal life.
4. A single center for the mesethmoid during the first year after birth.

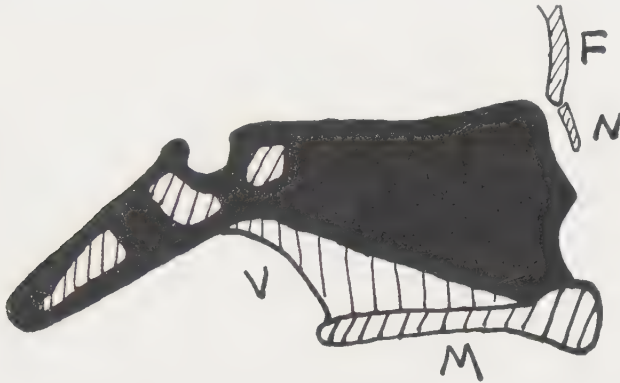


Fig. 2 Human mid-line cranial base in late fetal life. The ossification centers for the basi-occipital, postsphenoid and presphenoid elements are shown in the cartilage. V, vomer; M, maxilla; F, frontal; N, nasal.

These various parts unite with one another as follows:

1. The two parts of the sphenoid unite in man during the last month of fetal life. They are united at birth.
2. The mesethmoid unites with the facial parts of the ethmoid by ossification of the cribriform plate between the first and third year.
3. The occipital unites with the sphenoid between 17 and 20 years of age.

At birth the basal part of the occipital is ossified and the two parts of the sphenoid have just united. The mesethmoid has not yet ossified so that the nasal septum is still entirely cartilaginous except for the vomer at its lower edge. The spheno-occipital synchondrosis is in the form of a bilateral epiphyseal cartilage contributing to the growth of both the occipital and sphenoid bones.

The growth of the cranial base

In tables 1 and 2 the growth of the whole cranial base as measured from basion to nasion is shown in fetal and post-natal life. For comparison, data on the growth of body length (crown-heel) and of the cranial circumference are also included. In all cases the figures are the percentage of the adult size reached at each period of growth. At the 14th week

TABLE 1
Growth of body length, cranial base, and head circumference
Fetal life
 (Shown as a percentage of adult dimensions)

AGE IN WEEKS	BODY LENGTH ¹	CRANIAL BASE LENGTH ²	HEAD CIRCUMFERENCE ³
14	7	21	19
16	9	26	23
18	12	30	28
20	14	34	33
22	16	37	38
24	18	41	42
26	19	44	—
28	21	45	47
30	23	47	51
32	24	50	55
34	26	53	57
36	27	54	60
38	28	56	62

¹ Data for body length from Scammon and Calkins in Krogman ('41).

² Data for cranial base from Ford ('56).

³ Data for head circumference from Pfuhl in Krogman ('41).

of fetal life both the cranial base and head circumference have reached approximately the same proportion of their adult size, the cranial base being slightly ahead of cranial circumference. By the 22nd week the head circumference begins to draw ahead in the rate of its growth, and is somewhat ahead of the cranial base at birth. During the first and second year after birth, however, there is a great spurt in brain growth, as illustrated by the increase in head circumference from 65 to 90% of the adult size. The cranial base does not reach 90% of its adult size until about the 13th year.

Growth of the body as a whole is more constant than growth of the cranial base and head circumference. While head circumference shows a great spurt in growth immediately after birth (first to third year in association with growth of the brain (Keith, '31), the cranial base grows most rapidly from the 14th to the 32nd week of fetal life, with a period of less rapid growth during the last two months, a second spurt during the first years after birth, and a gradual slowing down after about the 7th year.

TABLE 2

*Growth of body length, cranial base and head circumference
Birth to adult life*

(Shown as a percentage of adult dimensions)

AGE	BODY LENGTH ¹	CRANIAL BASE (B-N)	HEAD CIRCUMFERENCE ¹
Birth	28	55 (21) ²	65
2 yrs.	50	70 (22)	90
4 yrs.	59	75 (15)	93
6 yrs.	66	80 (15)	95
8 yrs.	72	86 (32)	97
10 yrs.	78	89 (12)	98
13 yrs.	85	90 (12)	99
15 yrs.	91	91 (10)	99.6
18 yrs.	98	96 (8)	99.8

¹ Data for body length and head circumference from Kornfeld in Krogman ('41).

² Figures in parentheses = number of skulls measured.

Table 3 shows the growth of the various segments of the cranial base. The figures given are the actual measurements. It will be seen that, while the growth of the posterior (basion-pituitary) and anterior (frontal) segments show a growth pattern similar to that of the cranial base as a whole, the middle (ethmoidal) segment reaches adult dimensions by about the 7th year. (See also De Coster, '51; Scott, '54; Björk, '55). This early stabilization of the ethmoidal region is overlooked in the use of measurements of the anterior cranial base taken from the pituitary fossa to nasion (Brodie, '41; Grossman and Zuckerman, '55) as this measurement includes the frontal bone which continues to increase in thickness until adult life.

The available growth sites in the human cranial base after birth are:

1. At the foramen magnum. Unlike the anthropoid apes (Keith, '10) the foramen magnum in man does not show any evidence of backward migration.

TABLE 3
Growth of cranial base segments

AGE		B-N ¹	B-P ¹	P-C ¹	C-N ¹
Birth to two weeks (4) ²	mean	54	22	29	4
	range	(48-58)	(21-23)	(25-32)	(3-5)
1-3 yrs. (16)	mean	73	32	39	7
	range	(68-79)	(28-35)	(34-44)	(4-8)
4-7 yrs. (11)	mean	80	35	44	9
	range	(72-91)	(31-38)	(40-48)	(7-11)
8-13 yrs. (12)	mean	90	42	46	10
	range	(83-96)	(38-45)	(43-50)	(9-12)
14-20 yrs. (15)	mean	97	46	47	14
	range	(86-106)	(43-49)	(45-50)	(11-20)
Adult M + F	mean	98	47	47	16

¹ B = basion, P = pituitary point, N = nasion, C = foramen caecum.

² Figures in parentheses in first column = number of skulls measured.

2. At the speno-occipital synchondrosis. This is an important growth center until the beginning of adult life. It has been shown (Scott, '54) that it is situated in such a position relative to the coronal and lambdoid sutures as to influence the growth of the cranial vault in the antero-posterior dimension (fig. 3).

3. The speno-ethmoidal and fronto-ethmoidal sutures. These with their lateral extensions, the fronto-sphenoidal sutures at the floor of the anterior cranial fossa, join the coronal suture system at pterion and are situated in the same coronal plane as the retro-maxillary suture systems (in the pterygo-palatine fossa). As, however, the distance from pituitary fossa to foramen caecum remains constant after about the 7th year, there is probably little growth at these sutures after the end of the first decade (fig. 4).

4. The frontal bone increases in thickness at the glabella region by surface deposition until adult life (Keith and Campion, '21; Björk, '55), and this part of the bone is invaded by the frontal air sinus, especially during adolescence.

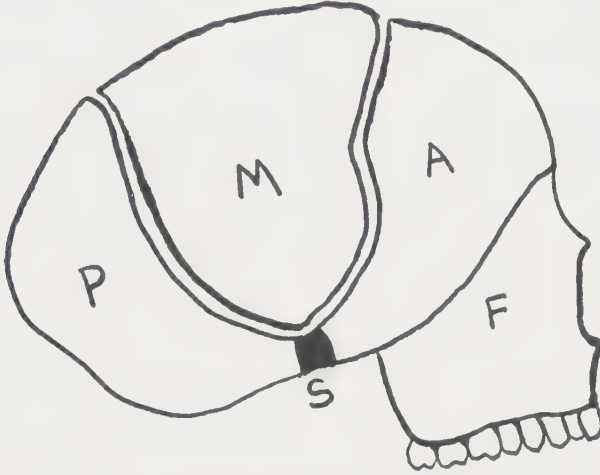


Fig. 3 Diagram to show the position of the spheno-occipital synchondrosis relative to the coronal and lambdoid suture systems and the cranial segments. P, posterior cranial segment; M, middle cranial segment; A, anterior cranial segment; F, upper facial skeleton; S, synchondrosis.

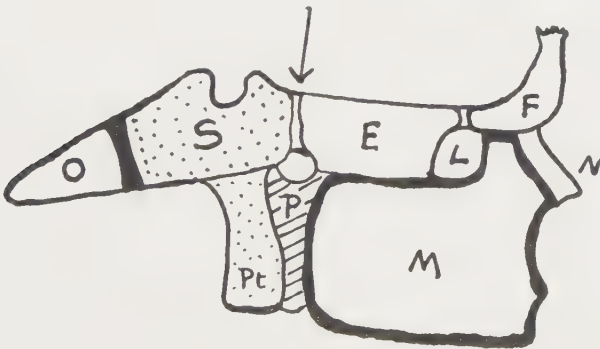


Fig. 4 Diagram to show the position of the spheno-ethmoidal suture relative to the retro-maxillary sutures in the pterygo-palatine fossa region of the upper facial skeleton. O, basioccipital; S, sphenoid; E, ethmoid; Pt, lateral pterygoid plate; F, frontal; N, nasal; M, maxilla; P, palatine; L, lacrimal. Arrow indicates position of spheno-ethmoidal suture.

The cranial base and the cranium

Table 4 shows the degree of correlation between the size of the cranial base and cranial capacity (brain size). The data are from the great series of 19th century Scottish skulls measured by Young ('17). Three hundred and seventy-seven male skulls have been divided into four groups according to their cranial base (basion to nasion) length.

- (a) Cranial base length 90–95 mm (37 skulls).
- (b) Cranial base length 96–100 mm (167 skulls).
- (c) Cranial base length 101–105 mm (141 skulls).
- (d) Cranial base length 106 + mm (32 skulls).

The average length of the cranial base for the series is 100.37 mm.

It will be seen that the larger skulls tend to have the larger cranial base but the range of variation for cranial size is quite great for each group. That is, the cranial base is not directly correlated with growth of the brain. The relative independence of the size of the cranial base and cranial capacity is further illustrated in table 5 from data supplied by Hrdlicka ('39) on micro- and macro-crania. It will be seen that in the female microcrania the range for cranial base length, 82–95 mm, does not differ much from the normal range of 84–100 mm, while the average value of 85.1 mm is not greatly below the normal of 93 mm as compared with the difference in the cranial capacity. The comparison between the large crania and the normal shows even less difference in regard to the cranial base measurement.

Tables 6 and 7 show the degree of correlation between cranial base length, cranial capacity and the cephalic index. It will be seen that for skulls of a given cranial base length there is a slight tendency for the larger crania to be brachycephalic. Howells ('41) found a correlation coefficient of -0.54 between cranial base length and cranial index in the Gallen crania. Taking $0.5 \pm$ as significant (Smart, '38) this is just significant. Again, there is a very wide range of variation in these correlations as was shown by Huxley in

TABLE 4
Correlation of cranial base length and cranial capacity. Scottish series. Male skulls
 (Data from Young, '17)

CRANIAL BASE LENGTH	CRANIAL CAPACITY, CM ³						
	-1200	1210-1300	1310-1400	1410-1500	1510-1600	1610-1700	1700 +
<i>mm</i>							
90-95 (37) ²	3	27	24	24	19	3	0
96-100 (167)	4	8	34	32	17	5	1
101-105 (141)	0	3	21	37	24	11	3
106 + (32)	0	0	5	19	41	17	19

¹ Distribution shown as a percentage of total in each group.

² Figures in parentheses = number of skulls.

TABLE 5

Cranial base length in microcrania and macrocrania
(Data from Hrdlicka, '39)

	MICROCRANIA ALL FEMALE, CHIEFLY PERUVIAN	MACROCRANIA ALL MALE, ALL RACES
Range of cranial capacity	940-1050	1750-2100
Range of cranial base length	82-95	94-122
Average of cranial base	85.1	104.3

Normal skulls
(Data from MacCurdy, '23 and Young, '17)

	50 PERUVIAN (FEMALE)	100 SCOTTISH (MALE)
Range of cranial capacity	1020-1410	1250-1930
Range of cranial base length	84-100	92-112
Average of cranial base	93	100.96

TABLE 6

Correlation of cranial base, cranial capacity and cephalic index
Male skulls

(Based on data from Young, '17)
Cranial base = 100 mm (46 skulls)

CRANIAL CAPACITY ¹	CEPHALIC INDEX ²	CRANIAL CAPACITY	CEPHALIC INDEX
1200	76.8	1460 (2)	74.7, 77.5
1290	73.2	1470 (2)	74.1, 74.5
1300	73.4	1480 (2)	76.4, 75.8
1310 (2)	72.9, 74.7	1490	74.3
1320 (2)	74.5, 69.4	1500 (2)	72.3, 74.5
1330	71.6	1510	77.0
1340 (2)	73.8, 72.9	1520 (2)	72.9, 73.1
1350 (2)	73.9, 74.5	1530	70.6
1370 (2)	70.7, 73.1	1540	76.5
1380 (2)	75.5, 75.0	1550 (2)	76.3, 71.5
1390 (2)	72.9, 73.3	1570	77.6
1410	69.8	1630 (2)	74.0, 77.6
1420 (3)	69.8, 71.3, 77.2	1710	76.0
1430	77.6		
1440	72.2		
1450 (2)	73.1, 74.1		

¹ Range of cranial capacity 1200-1710.

² Range of cephalic index 69.4-77.6.

1867 when he compared in detail two skulls, one the widest (C.I. = 97.9) and the other the narrowest (C.I. = 62.9) he had met. The cranial base length was the same in both. In commenting on this he wrote: "Brachycephaly and dolichocephaly are not necessarily connected with the shortening and lengthening of the base of the skull . . . their most extreme forms may arise exclusively from modifications of the side walls and roof of the cranium."

TABLE 7

Correlation of cranial base, cranial capacity and cephalic index
Cranial base = 100 mm (48 skulls)

CRANIAL CAPACITY	CEPHALIC INDEX			
	72 and -	74 and -	75 and +	77 and +
1440 - (26)	6	16	5	2
1450 + (22)	2	7	9	4

Among different living human races the average cranial base length for male skulls extends from 95 mm in Bushmen to 108 mm in the Eskimo. In females the measurements are always slightly less; the average being 93 mm in Bush skulls and 103 mm in the female Eskimo (Martin, '28). As there is some correlation between brain size and body size, it might be expected that a certain degree of correlation would exist between the length of the long bones and the cranial base. Howells ('41), however, found the very low value of -0.015 for the correlation coefficient between length of the femur and the basion-nasion length, and stated that stature has no apparent relation to either the size or the shape of the head for Early Christian Irish.

The cranial base and the facial skeleton

The facial skeleton (excluding the mandible) is closely related to the anterior cranial segment of the skull (fig. 4) which consists of the frontal, mesethmoid and sphenoid bones, and this upper part of the face is closely related in its develop-

ment and growth with the anterior half of the cranial base (from pituitary fossa to nasion) that is, the middle and anterior segments. In early fetal life the cartilage of the cranial base is continuous with that of the nasal capsule (fig. 2). The ossification centers which appear in the cranial base have already been described. In the cartilage of the nasal capsule the ossification centers of the facial ethmoid and the inferior turbinate bones appear during fetal life and are fully ossified by the time of birth. Centers for the maxillae, zygomatic, palatine and lacrimal bones appear in condensations of mesoderm in close relation to the nasal capsule early in fetal life, while the vomer appears as an ossification center in the perichondrium bordering the lower edge of the cartilage of the nasal septum. With further development these facial bones come into relationship with one another at various sutures which together make up two great facial suture systems. One of these, the circummaxillary system, separates the maxilla from the frontal, lacrimal, facial ethmoid, palatine, zygomatic and vomer, while the craniofacial system separates the lacrimal, facial ethmoid, palatine, zygomatic and vomer from the bones of the anterior cranial segment: the frontal, sphenoid (greater wing of median pterygoid plate and body) and mesethmoid (perpendicular plate of ethmoid). These suture systems are arranged so as to permit growth of the upper facial skeleton to take place in a downward and forward direction (fig. 4) and it has been suggested (Scott, '53, '54) that this growth is regulated to a considerable extent during fetal life and early childhood by the growth of the cartilage of the nasal septum.

In man the sutures between the back of the maxilla and the vertical plate of the palatine and between the palatine and the median pterygoid plate and the suture line across the floor of the anterior cranial fossa (spheno-ethmoidal and fronto-ethmoidal) make up a suture system which would permit the bones in front of the system (frontal ethmoidal, palatine and maxillae) to grow forward from the sphenoid. In so doing space would be made for the maxilla to grow backwards and

thus make room for the erupting molar teeth. This is the classical theory of maxillary growth (Keith, '02; Brodie, '42). We have already seen, however, that growth of the cranial base from pituitary fossa to foramen caecum, that is, across this suture system, ceases about the 7th year and, while it is possible that the maxilla may continue to move forward relative to the other facial bones after this period, there is no evidence that this takes place to any considerable extent. It would appear that growth of the upper face can be divided into two phases: (a) an early phase during fetal life and early childhood when growth of the anterior half of the cranial base and nasal capsule (especially the nasal septum) thrusts the facial bones downwards and forwards and allows growth to take place at the facial and anterior cranial sutures, and (b) a later phase, from about 7 years until adult life, when growth at the facial sutures has ceased and growth of the upper part of the face is produced entirely by surface deposition associated with internal absorption of bone to allow for increase in size of the nasal cavities, air sinuses and the oral cavity.

Although growth of the upper facial skeleton is closely related with the growth of the anterior half (middle and frontal segments) of the cranial base, it is possible for a normal facial skeleton to develop in relation to a reduced cranial base. This is shown by a study of the microcrania and macrocrania described by Hrdlicka ('39). He writes: "In no one of the specimens, small or large, is there any significant abnormality of the palate, the dental arches or the teeth." This relative independence of the growth of the cranial and facial parts of the skull is illustrated in table 8, in which certain measurements of 10 of the microcrania from Hrdlicka are compared with the range of variation of 50 normal Peruvian skulls (from MacCurdy, '23). For cranial length, 8 of the microcranial skulls are below the normal range; for cranial width, none; for cranial base length, two; for orbital height, palate width and bizygomatic width, one; and for upper facial height and nasal height, none.

TABLE 8
Cranial and facial measurements in microcrania
 (Data from Hrdlicka, '39 and MacCurdy, '23)

	1	2	3	4	5	6	7	8	9	10	RANGE OF NORMAL PERUVIAN SKULLS
Cranial capacity	920	940	955	970	970	970	980	990	995	1000	1020-1410
Cranial length	144	156	152	153	148	147	159	157	157	159	158-180
Cranial width	130	130	130	130	143	134	124	132	130	126	119-139
Cranial base length	88	88	92	82	88	88	82	89	91	94	84-100
Upper face height	61	64	64	57	61	64	56	63	60	65	55-71
Orbital height	31.5	33	30.5	33	33	34	32.5	30.5	32.5	32	31-41
Nasal height	44	46	45.5	41.5	43	49.5	42.0	42.5	43.5	45.5	40-52
Bizygomatic width	121	116	120	113	123	122	117	121	127	124	115-130
Palate width	56	63	63	52	57	57	—	56	60	59	53-66

The relationship between growth of the cranial base and the facial skeleton is further illustrated by conditions such as achondroplasia in which there is a failure in the growth of the cartilage of the cranial base. In two newborn children described by Hunter ('33), the cranial base length was 23 mm and 25 mm. As, however, the cartilage of the nasal capsule is also involved, the reduction of the upper facial skeleton found in this condition (Brash, '56) is probably more directly related to this site of cartilage growth failure than to the failure of growth at the spheno-occipital synchondrosis. The ability of the upper facial skeleton to compensate for failure of growth of the cranial base and to a lesser extent for failure of growth of the cartilage of the nasal capsule, is probably dependent on surface deposition, which is independent of suture growth. Even in skulls which show a marked reduction in the size of the upper part of the face, in the region of the bridge of the nose, there is often a normal development of the alveolar process and of the lower part of the face. This is well illustrated in the case of a microcephalic skull from the Anatomy Museum of the Queen's University (fig. 5). The cranial capacity is 455 mm, cranial length 140 mm, cranial width 103 mm, cranial base length 94 mm, upper facial height 68 mm, orbital height 32 mm, nasal height 51 mm, bizygomatic width 106 mm, and the external palatal width 63 mm. Of these measurements, cranial capacity, cranial length, cranial width, and bizygomatic width are well below the normal range, while the other measurements are within the range of normal, although the cranial base is short for a male skull. The alveolar arch, however, is very large and perfectly formed.

The flexure of the cranial base

In man the cranial base shows a higher degree of flexure of the cranial base than in any other animal. Duckworth ('04) states that the gradual decrease in the size of the sphenoethmoidal angle from the lower mammals to man gives a good indication of the gradual increase in the development of the

frontal lobes of the brain. Like Huxley (1867) and Topinard (1890) he measures this angle between the two lines, one from basion to spheno-ethmoidal suture (prospenion) and the other from the spheno-ethmoidal suture to nasion. Ford ('56) shows that during fetal life the angle increases from 131.5°



Fig. 5 Microcephalic skull with a well developed dental arch.

at 10 weeks to 150.5° at birth, a total increase of 19° . This, of course, involves a flattening or straightening out of the cranial base during fetal life. What happens after birth is less certain. Topinard, quoting Welcker, gives average values of 140° for 6 newborn infants, 137° for 10 children from 10–15 years of age, 138° for 30 German women and 134° for 30 German men. The number of skulls in each group is, however,

quite inadequate to allow for the wide range of individual variation. Zuckerman ('55), using prosphenion as the place of inflexion gives a value of 151.9° as the mean for 8 skulls under one year; 148° for 12 skulls between one and two years; 144.1° for 9 skulls between 3-5 years; 144.5° for 28 skulls between 6-8 years; 142.6° for 4 skulls between 9-14 years; 145.1° for 20 skulls between 15-21 years and 148.8° for 99 adult skulls. The slight differences in the angle at various ages are probably the expression of the range of variation. Björk ('55), using the middle of the pituitary fossa as the meeting point of the anterior and posterior cranial axial lines, gives the mean value of the angle as 130.8° at 12 years of age, and 131.6° at 20 years of age. He states that in some individuals the angle increases (maximum 5°), while in others it decreases (5.5°). He used serial x-rays of the skull in his studies. Young ('17) in 98 adult male skulls from his Scottish series, using phosphenion as the site of inflexion, found the range of variation to extend from 137° to 170° .

It should be pointed out that nasion is not altogether a satisfactory point for measuring the angle of flexure. It varies in its relationship to the foramen caecum (the true anterior end of the cranial base), and it also changes its position with age (Scott, '56). The position of nasion relative to the anterior end of the true cranial base also shows wide variation in different animals.

A more important question, however, is the exact site at which the bending process occurs. It is usually considered that this takes place at the meeting of the two bounding lines, that is at the spheno-ethmoidal suture (prosphenion). This is unlikely as it would involve a thrusting backwards of the maxilla and palatine bones against the median pterygoid plates in the facial skeleton. Björk ('55) considers that the rotation takes place at the spheno-occipital synchondrosis. There is, however, another site which persists in man up to birth and in monkeys and lower mammals for a much longer period, that is, at the synchondrosis between the presphenoid and post-sphenoid elements of the body of the sphenoid bone.

Cameron ('24) believed that the flexion of the cranial base occurs in the region of the pituitary fossa and it is interesting to note that the synchondrosis between the two parts of the sphenoid as seen in the *Rhesus* monkey (fig. 6) is related to the front of the fossa. It is probable that this is the main site of cranial base flexure during fetal life. Changes after birth in man, if in fact they do occur, and if they are not due

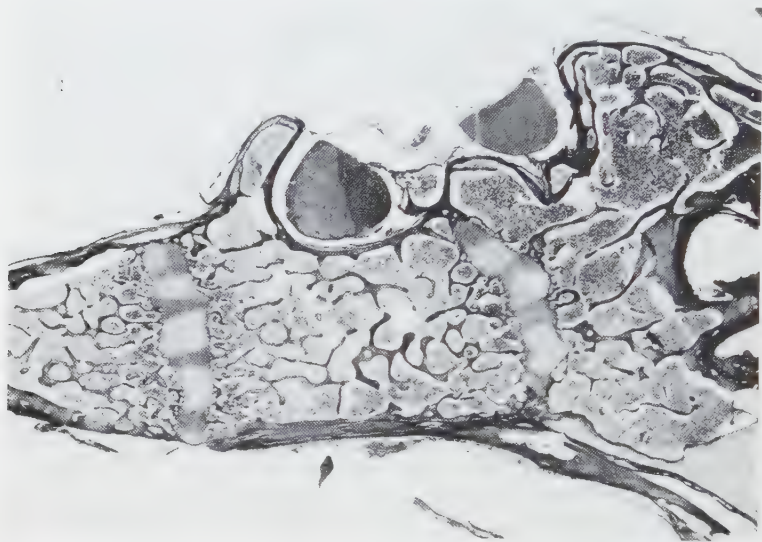


Fig. 6 Cranial base in *Rhesus* monkey about three years of age. The sphenoccipital and sphenoidal synchondrosis are both shown. The latter is closely related to the front of the pituitary fossa above and to the septal cartilage below.

to changes in the position of nasion, are probably due, as Björk suggests, to changes at the sphenoccipital synchondrosis which can act as a secondary site of flexure. It would appear that the failure of the angle to increase in man after birth is due not to growth of the frontal lobes of the brain but to the early union of the two parts of the body of the sphenoid bone which unite the anterior and posterior parts of the cranial base across the main site of flexure. The straightening out of the cranial base in animals other than man and the anthropoid apes so that it reaches 180° or more in adult

animals (Duckworth, '04) appears to be related to the direction of growth of the cartilage of the nasal septum. In a fetal dog the direction of growth of the cartilage is vertical, while in an adult animal it is horizontal (Bolk, '26; de Beer, '51). In man it remains more or less vertical. As, however, the nasal cartilage is itself an extension of the cartilage of the cranial base, a change in its growth direction will involve the anterior half of the cranial base. In the *Rhesus* monkey, in which the synchondrosis between the two parts of the sphenoid persists until after the eruption of the second permanent molars, Ashton ('57) describes a steady opening out of the angle of the cranial base up to this period. One hundred and forty-nine degrees is the average for 14 female animals between birth and alignment of the first permanent molars; 155° is the average for 9 animals between eruption of the permanent incisors and eruption of the second molars, and 164° is the average before eruption of the canines and third molars. After this time his figures show a slight reduction but this may be due to individual variation among the small numbers of animals used. The average given for 12 adult animals is 160°.

Comparative anatomy of the cranial base

Table 9 gives some information from various sources for cranial base length and the spheno-ethmoidal angle in the dog, *Rhesus* monkey, baboon, chimpanzee, orang and gorilla. Much of the apparent difference between the values for the angle shown among the primates appears to be due to the position of nasion relative to the foramen caecum. In the adult baboon and *Rhesus* monkey, nasion, as in man, is at about the same level as the floor of the anterior cranial fossa, while in the gorilla and orang it is well above this level. In table 9 the values of the spheno-ethmoidal angle provided by Cameron ('30) and Ashton ('57) are both given. Cameron used nasion as his anterior point; Ashton in an attempt to avoid the faults of this position used a point where the mid-sagittal plane is crossed by a line joining the upper limits of the frontal proc-

TABLE 9
Comparative measurements of cranial base
 (Data mainly from Ashton, '57 and Cameron, '50)

	DOG	RHESUS	BABOON	ORANG	GORILLA	CHIMPANZEE	MAN
Cranial base length				95	120	108	100.38
Basion-pituitary point (Ashton)		27	44	47	58	44	48
Pituitary point-nasion (Ashton)		37	46	55	73	56	59
Pituitary point-foramen caecum				32	35	41	48
Spheno-ethmoidal angle (Ashton)		161°	148°	167°	169°	159°	133°
Spheno-ethmoidal angle (Cameron)	208°	173°	—	161°	178°	159°	131°

esses of the maxillae. He states that this lies approximately along the floor of the anterior cranial fossa, but even this point lies well above the level of the foramen caecum in these animals, (anterior end of the cribriform plate). This is because in many animals, including the anthropoid apes, but not in man, the cribriform plate and foramen caecum lie at the bottom of a deep olfactory pocket (Cameron, '30). Even in these cases, however, the foramen caecum probably represents more accurately than any other point the true anterior end of the cranial base.

TABLE 10

The sphenothmoidal angle in 6 chimpanzee skulls, using foramen caecum as the anterior point

NO.	DENTAL CONDITION	ANGLE
1	Deciduous dentition complete	155°
2	Deciduous dentition complete	140°
3	Deciduous dentition complete	160°
4	1st permanent molar erupting	145°
5	1st permanent molar in occlusion but deciduous molars still in place	145°
6	Adult	160°

In the higher anthropoid apes, as in man, the synchondrosis between the two parts of the sphenoid closes early, probably at or about the time of birth. However, Ashton ('57) shows an increase in the angle up to adult life in the anthropoid apes as in Rhesus monkeys. In table 10 I have given the measurements of the angle in 6 chimpanzee skulls using foramen caecum as the anterior point. Although the number of skulls is quite inadequate, the table shows the need for measuring a much larger number of skulls in order to eliminate the individual variation factor and indicates that more work still requires to be done in regard to the comparative anatomy of the cranial base.

TABLE 11
*Cranial base, cranial capacity and cephalic index in human fossils*¹

	PITHECANTHROPUS	SINANTHROPUS	H. SOLOESENSIS	NEANDERTHAL	UPPER PALAEOLITHIC	MODERN MAN
Cranial base length:						
Range	108-113	—	113-114	98-125		
Average	110.5	105.5	113.5	111	104.8 (M) 99.0 (F)	102.7
Cranial capacity:						
Range	775-900	915-1225	1035-1255	1220-1610		
Average	822	1043	1100	1400		1300
Cranial index:						
Range	73.2-79.3	71.4-72.6	66.2-76.7	68.2-76.3		
Average	76.3	72.2	72.0	73.3		72.8
Cranial base angle						
				Early		
				101-117		
				Late		
				123-135		

¹ From Weidenreich ('43), Howell ('51) and Morant ('30).

Cranial base in fossil man

Table 11 gives the cranial base length, cranial capacity and cranial index in some human fossils (from Morant, '30; Weidenreich, '43, '45), and the cranial base angle in Neanderthal skulls (Howell, '51). Cranial base length was greater in early man and has tended to decrease with increase in cranial capacity. Although the number of skulls, on which the evidence of the change in the cranial base flexure in Neanderthal man is based, is limited the difference is significant and interesting.

DISCUSSION

Perhaps the most interesting problem regarding the morphology of the cranial base is concerned with the high degree of flexure which is characteristic of the human skull. The decrease in the angle of flexure is associated with an increase in the height, and a reduction in the length, of the cranial vault (Weidenreich, '41, '47; Björk, '55), but from what we know of the development and growth of the cranial base, there is no evidence that these changes are the direct result of brain growth. The brain appears to adapt its form to that of the skull base upon which it rests, and both brain growth and cranial base growth contribute to the form of the cranial vault.

If the cranial base is grossly underdeveloped, as in achondroplasia, or if one of its growth centers is destroyed growth of the brain tends to provide the necessary room by a rounding (brachycephalization) of the vault. Weidenreich ('45) has pointed out the correlation between the expansion of the brain (relative to body size) and reduction of the jaws among certain breeds of dog. He states that the changes are due to the expansion of the brain and that the brain of a dwarf breed of dog, such as the King Charles spaniel, is much too large for the reduced skull and consequently needs for its accommodation all the space in the skull which can be made available. The result is an enormous expansion of the brain case in all its dimensions and enormous reduction of the jaws and teeth. He concludes that the principle of the correlation shown

among different races of dog is exactly the same as that which is manifested in the phylogenetic transformation of the human skull. As, however, the cause of the variations shown on the skulls of dwarf breeds of dog are probably related to achondroplasia and the reduction of the facial skeleton is a consequence of this rather than an increase in brain size, phylogenetic comparisons are perhaps somewhat inapt unless one postulates that modern man is an achondroplastic mutant as Keith ('11) suggested that Neanderthal man showed some of the characteristic traits of acromegaly.

Elsewhere, however, Weidenreich ('43, '47) suggested that the bending of the cranial base is a final step in the adaptation of the skull to new static and dynamic conditions necessitated by the acquisition of the upright posture. That there is some correlation between cranial base flexure and prognathism of the facial skeleton is indicated by the phylogenetic changes in the skull form shown by human evolution from *Pithecanthropus* to modern man, and the very interesting "reversion" on the part of late Neanderthal fossils in which it appears that the face became more prognathous and the cranial base angle more opened out. This correlation although suggestive is not, however, an inevitable process of evolution. The baboon, which develops a very massive and prognathous facial skeleton, does so in relation to a cranial base angle of 148° (Ashton, '55) which is considerably less than that of the Rhesus monkey and is in fact closer to the human average of 133° than any other higher primate.

Table 12, constructed from the data supplied by Young ('17), shows the correlation between the spheno-ethmoidal angle and the spheno-maxillary angle. The latter is a measurement of facial prognathism. It will be seen that there is a general but not exact correlation between cranial flexure and facial prognathism.

From a consideration of the available evidence it would seem that the cranial base angle is, however, in a general way related to the growth of the upper facial skeleton. It has been pointed out that the anterior part of the chondrocranium is

continuous with the cartilage of the nasal capsule and that growth of the nasal septum involves the cranial base from the sphenoid to the frontal bone. In some animals (de Beer, '37) the mesethmoid is absent and the presphenoid ossification centers invade the septal cartilage replacing the perpendicular plate of human anatomy. This spread of ossification from the sphenoid region of the cranial base into the nasal septum emphasizes the structural continuity of these parts. In animals other than man and the higher anthropoids, the synchondrosis between the postsphenoid and presphenoid persists for a considerable time after birth and even in man it is an active site of growth during fetal life when the cranial

TABLE 12

Correlation of cranial base flexure and facial prognathism

(Data from Young, '17)

SPHENO-ETHMOIDAL ANGLE	SPHENO-MAXILLARY ANGLE			
	67-77°	78-83°	84-89°	90° +
136-141°	4	1	0	0
142-147°	3	9	8	0
148-153°	1	15	13	1
154-159°	1	5	19	6
160° +	0	2	2	10

base flexure is established. This synchondrosis is continuous with the septal cartilage in most animals until after the union of the perpendicular plate with the vomer, and in many animals the septal cartilage continues to extend back to the sphenoid in a bony canal or tube even after union of the septal bony elements (Scott, '53). Bolk ('26) has suggested that the essential nature of the cranial base flexure is due to a failure of the angle to open out during fetal life. In early fetal life all mammals show a flexure which, however, usually disappears or becomes reversed ($180^\circ +$) by the time of birth except in the primates and especially in man. It would seem therefore that if the face does not change its fetal position relative to the cranium, the cranial base remains flexed.

Even if we can establish a correlation between facial growth and the cranial base, it still remains for us to face the fundamental problem of why these changes began in the lower primates (*Tarsius*) and reached their full development in man. We are back to Weidenreich's theory of a correlation between skull form and the upright posture. In animals which move on 4 limbs and which carry the skull at the front end of a horizontal vertebral column, the facial skeleton must move outwards and forwards from its developmental position below the skull to a position in front of the cranium. If this does not happen the most satisfactory compensating mechanism would be to sit up (as monkeys and apes, and certain rodents, do) and then stand up (as men do). Both these actions liberate the forelimbs to become organs of manipulation and discriminative sensation, and this in relation with the establishment of connections within the brain with the centers for the sense organs of sight, smell, taste, etc., may have been the biogenetic stimulus necessary to set the brain on its dramatic human evolutionary expansion. The anatomy of the Australopithecinae would seem to indicate that brain development followed the acquisition of the upright posture rather than determined it.

In an interesting paper Du Brul ('50) points out that lagomorphs, rodents and marsupials, animals with general horizontal body orientation, have skulls in which facial, cranial and body axes are in the same general horizontal line as compared with animals assuming relatively erect posture and locomotion habits, in which changes in orientation of these axes take place in relation to the change in body posture. Only in the primates, however, has there occurred any great change in the size of the brain, and only among the primates does the cranial base angle fall much below 180°.

This would seem to indicate that the growth of the primate brain, although correlated with the upright posture, was not a necessary consequence of the change in position of the body axis. It is probably more directly correlated with the use of the forelimbs which have developed a much greater repertory

of skills among the primates than in any of the rodents or marsupials. As Wood Jones ('16) puts it: "In the primates, owing to the preponderant use of the forelimb, there is no need for a mouth which reaches out for food, or for a mouth which seizes food or kills it when seized, all these functions being discharged by the mobile and grasping forelimb." We would, however, express it rather differently in suggesting that the forelimb came into use to compensate for failure of development of the facial skeleton. Reduction of the face is often associated with reduction of the dentition, but the edentates and other animals show loss of teeth without any reduction of the facial skeleton.

Elsewhere (Cole, '54; Scott, '54) it has been suggested that a function of the nasal cavities in many animals is that of regulating heat loss from the body. This is associated with the complexity of the inferior turbinate processes, and especially the maxillary turbinates, which require a well developed upper facial skeleton to house them. In the primates there is a progressive loss of turbinate complexity and this is especially marked in man. It is possible that with the development of the cutaneous heat-regulating mechanism which reaches its fullest complexity in man, the nasal mechanism has fallen progressively into disuse, and that this, rather than loss of the teeth, is the main factor responsible for the reduction of the facial skeleton among the higher primates.

It is interesting to notice that in the chimpanzee the facial skeleton, which supports the alveolar processes and the relatively large teeth, is about the same size as in man and the reduction of the upper face in relation to the nasal cavities is much the same as in man. This is partly hidden by the development of the facial buttress system, including the supra-orbital bars which are, however, related to the masticatory apparatus. The alveolar prognathism of the living anthropoids appears to be a secondary specialization and to have been less extensive in fossils such as *Proconsul*. Among the anthropoid apes alveolar prognathism developed in relation to an enlargement of a certain type of dentition (large incisors and canines

but moderate-sized cheek teeth). Among the Australopithecinae it appears to have developed, probably independently, in relation to a different kind of dentition (small incisors and canines but massive cheek teeth). Early man had a moderate degree of alveolar prognathism which modern man is losing. These dental changes, however, do not in themselves account for the bending of the cranial base. They seem to be but morphogenetic pulsations superimposed upon a deeper and more continuous process underlying the progressive reduction of facial skeleton among the primates, and the face of the baboon and the gorilla are but secondary specializations superimposed upon this more basic theme. The secret beginnings of the human brain may have begun in the structure and physiology of its humble cousin the skin, and in nakedness the master of creation may have been born.

SUMMARY

1. The cranial base in its growth and morphology has a limited effect on the growth and form of the cranial vault and has but little relationship to growth of the brain.

2. The prepituitary half of the cranial base is closely related to the development and growth of the upper facial skeleton, and development of the facial skeleton is closely related to the flexure of the base.

3. In man most of the bending process takes place during fetal life and it probably occurs chiefly at the synchondrosis between the postsphenoid and presphenoid elements. In animals other than man and the anthropoid apes, this synchondrosis persists until after birth permitting a continuation of the bending processes.

4. As nasion bears a highly variable relationship to foramen caecum, the true anterior end of the cranial base, many measurements of the cranial base angle are unreliable for comparative purposes.

5. It is suggested that failure of the human face to alter its fetal developmental relationship to the cranium initiated the establishment of the fully upright posture and that this,

in association with sensory changes in the forelimbs and body skin, was responsible for the later phenomenal development of the human brain.

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CHANGES IN THE PROPORTIONS OF THE FEMALE FOOT DURING GROWTH

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THREE FIGURES

INTRODUCTION

It is possible to deduce general facts about changes in foot dimensions with age by taking detailed foot measurements of groups of children of different ages. For example, length growth curves may be derived by plotting average foot lengths for groups of children of consecutive ages against their respective average ages in years. Thus Hill and Isherwood ('48) showed the average length growth of South African school boys' feet to be 0.32 inches per year between the ages of approximately 6 and 16. At 16, on the average, the growth rate fell off rapidly. Similarly Isherwood ('50) gave the average length growth of South African school girls as 0.29 inches per year between the ages of 5 and 13, and showed that on the average, length growth virtually ceased between 13 and 14 years of age. In both these studies, evidence was also given of changes in the width/length and joint girth/length proportions of the feet at different ages, but for practical reasons dimensional changes were subsequently studied in relation to changing foot length and not changing age (Isherwood, '48, '51a, '51b; Hill and Isherwood, '49a, '49b, '49c, '50).

In Britain, Clapham ('50) analyzed results of surveys on school childrens' feet between two and 14 years of age and a group of 1,000 people ranging from 12 to 21 years old comprising subjects from schools, technical colleges, shops and factories. He demonstrated cessation of growth in length at

17 for males and 15 for females, on an average, and also showed that certain proportions in feet, such as joint girth/foot length ratio, varied with age.

Dick ('52), from a survey of girls' feet in New Zealand, illustrated virtual cessation of length growth for girls at 13 years, but continued joint girth increases for a further 18 months, thus again pointing to a change in girth/length proportions with age.

The tendency for foot proportions, and thus foot shape, to change with age may best be followed by calculating ratios of one dimension to another, and comparing these ratios at different ages. It is more usual to express such relationships in the form of an index, wherein the one dimension is expressed as a percentage of the other. Though anthropological literature abounds with the study of such body indices in relation to age, there is very little information regarding the human foot. Published growth statistics either make no mention of the foot, or are confined to changes in foot length. Occasionally reference can be found to foot breadth and length, from which a foot breadth index may be calculated. For example Tamburri ('33) recorded foot lengths and breadths of Italian boys and girls from birth to 12 years old. Foot breadth indices calculated from his results illustrate a rapid decrease in relative foot breadth between the ages one to 5, and thereafter a remarkably constant proportional growth of both boys' and girls' feet.

Further data regarding foot breadth index were published by Tedesco, ('31) and Grützner ('28), who respectively gave the following values for Italian males and Swiss girls:

TABLE 1
Foot breadth indices of Italian males and Swiss girls

AGE	13	14	15	16	17	18	19
Italian males	40.6	39.8	40.0	40.6	40.8	40.7	40.9
Swiss girls				↓ 39.0	↓ 38.8	↓ 38.8	↓ 39.8

It should be noted that the above values for foot breadth index (roughly 39 to 41) are considerably higher than those found by Tamburri for both boys and girls aged one to 12 (29 to 31). Whether this is due to different measuring techniques by different authors, or to an age or racial effect, cannot be determined. The index value of 39-41 is however more in keeping with values quoted by Wartenweiler ('43) who, in a survey of 1,200 Swiss subjects showed that for both males and females there was an initial drop in the foot breadth/length index from birth, and the value then remained virtually constant (between 38 and 39) until after the 16th year, when it increased slightly, approaching 41 in adults. This increase in breadth index Wartenweiler associated with the general broadening of the foot which occurs after cessation of body growth.

A further study of some 500 boys' and girls' foot lengths was described by Anderson, Blais and Green ('56), who again demonstrated length growth cessation in girls at the age of 13, and who related growth of the foot to stature and to length of lower leg. They also examined the proportions of the heel, mid-tarsus and metatarsus in relation to foot length by means of true annual serial measurements from birth to 18 years on a group of 20 children, and concluded that there was no significant change in the proportions of these segments.

There appears to be little other information available on changes in other proportions of the foot with age.

MATERIAL AND METHODS

As part of a series of foot surveys carried out by this Institute since 1947, South African European school girls' feet were measured in detail and photographed in a special apparatus which recorded foot plan and two profiles of the foot at rest, weight off. A full description of this apparatus has been given by Shuttleworth ('48), and details of the measuring methods and type of information extracted from the photographic records have been described by Hill and Isherwood in Leather Industries Research Institute publications already

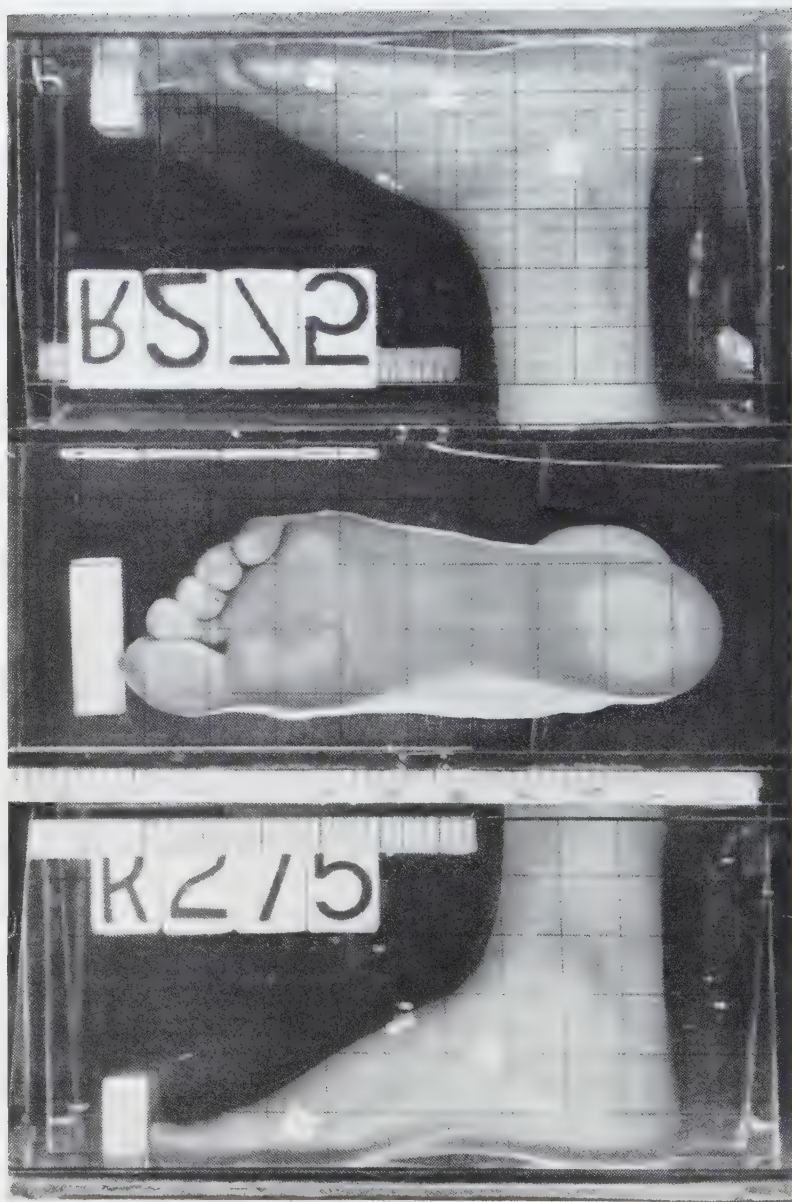


Fig. 1 (Photograph) A typical photographic record showing three views of a foot. Key points, marked with adhesive markers, serve as location points for measurements taken on the foot and from the photograph.

cited. Figure 1 illustrates a typical photographic record, and shows the markers placed on key points of the foot, which were used to locate subsequent measurements.

Records of girls' feet were taken in schools in Grahamstown, Eastern Province, South Africa, during 1947 and again early in 1949, and a number of girls had their feet recorded on both occasions, i.e., after an interval of some 18 months. During October 1956 it was found possible to re-photograph 41 of these girls' feet, so that changes in these individual feet could be studied after a further interval of 7½ years.

The present paper discusses these changes in detail. In 1949 the girls' ages ranged from 7 to 14 years, and in 1956 from 14 to 21 years. The group is therefore considered of particular interest, not only because of dimensional changes after a 7½-year interval, but because during that period the individuals had grown either from childhood to adolescence or from early adolescence to maturity, and in many cases the type of shoes worn had changed from flat heel school shoes to higher heeled fashion shoes. All the subjects were European children of English-speaking parentage.

Definitions

A number of dimensions and indices are used in the ensuing sections, and these are defined as follows:

Total foot length. The overall length in inches from the back of the heel to the tip of the longest toe, as measured with calipers (size stick).

Sole length. The length in inches from the back point of contact of the heel with the glass baseplate of the apparatus to the tip of the longest toe, as read from a photographic record. This measurement is therefore shorter than the corresponding total foot length.

Heel to ball length. Distance from the back contact point of the heel to a point opposite the first metatarsal head, measured from a photograph and along the center line of the foot.

Heel to outside joint length. Distance from the back contact point of the heel to a point opposite the fifth metatarsal head,

measured from a photograph and along the center line of the foot.

Heel to 5th metatarsal base. Distance from the back curve of the heel to a marker on the 5th metatarsal base prominence, measured from a photograph of the outside foot profile.

Joint width. The contact width of the forepart, taken from a photograph of the sole of the foot, and measured diagonally across the heads of the first and fifth metatarsals.

Heel width. The contact width of the heel, measured from a photograph of the sole, and at right angles to the foot centre axis. The position of this measurement was $\frac{1}{6}$ of the foot length, from the back contact point of the heel.

Joint girth. The girth of the foot, as measured by a tape running round the heads of the first and fifth metatarsals.

Instep girth. Girth of the instep, as measured by a tape running over the base of the 5th metatarsal and over a mark on the top of the instep, situated at half the total foot length.

Instep height. The vertical distance between the instep marker and the horizontal baseplate of the measuring apparatus.

Arch height. The vertical height of the Navicular bone prominence above the horizontal baseplate of the apparatus.

Calculated indices

$$\text{Width ratio: } \frac{\text{Heel width}}{\text{Joint width}} \times 100$$

$$\text{Foot breadth index: } \frac{\text{Joint width}}{\text{Total foot length}} \times 100$$

$$\text{Ball length index: } \frac{\text{Heel to ball length}}{\text{Sole length}} \times 100$$

$$\text{Outside joint index: } \frac{\text{Heel to outside joint}}{\text{Sole length}} \times 100$$

$$\text{5th metatarsal index: } \frac{\text{Heel to 5th Met. base}}{\text{Total foot length}} \times 100$$

$$\text{Joint girth index: } \frac{\text{Joint girth}}{\text{Total foot length}} \times 100$$

$$\text{Instep index: } \frac{\text{Instep height}}{\text{Total foot length}} \times 100$$

$$\text{Girth index: } \frac{\text{Joint girth}}{\text{Instep girth}} \times 100$$

$$\text{Arch index: } \frac{\text{Arch height}}{\text{Total foot length}} \times 100$$

RESULTS AND DISCUSSION

1. *Width ratio* (heel width/joint width)

The width ratio expresses the spread of the forepart relative to the heel, and therefore defines the plantar shape of the foot to some extent. It is, however, important to note that width ratio alone does not specify shape. For example, two feet of very *different lengths*, but with the same heel width and width ratio, will not necessarily have the same plantar shape. In general the longer foot will have a relatively narrower forepart, i.e., will show less forepart spread.

These two cases are illustrated in figures 2 and 3.

From detailed studies of the variation of width ratio on both boys' and girls' feet, the author has shown that this ratio is not directly dependent on foot length or on age, but that a full range of values from 57 to 74 may be encountered at each foot length between 6 and 10.5 inches. In other words feet of a given length or age are not characterized by a specific width ratio. For boys the general average width ratio over all foot lengths was found to be 66, and for girls 64. In the present study, the average value for width ratio for all the girls' feet measured was again 64.

A change of 4 units or less in the value of the width ratio is not considered important, as this represents a change of only 5-6%, and in the range of heel and joint widths under consideration, errors of 0.1 inch in either foot measurement would result in changes of three to 4 units in the calculated width

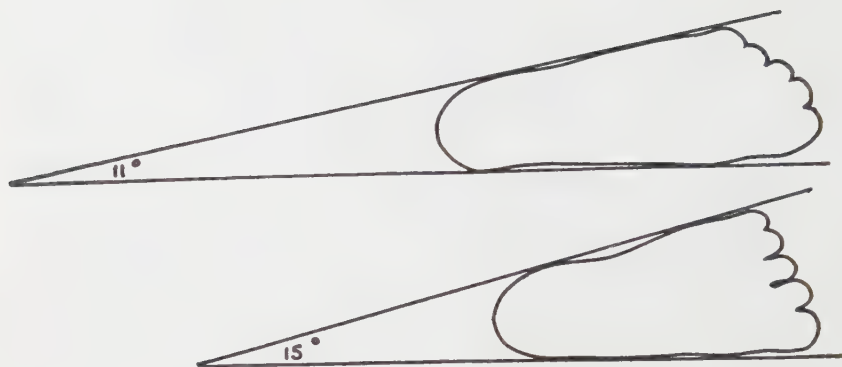


Fig. 2 (Drawing) These two feet have the same width ratio and the same heel width, yet they are very different in *shape*, the longer foot showing less forepart spread.



Fig. 3 (Drawing) Besides being of different length, these two feet have quite different *shapes*, yet they have exactly the same width ratio.

ratio. On this basis, alterations in the width ratio for the present set of observations are summarized as follows:

Over a period of 18 months growth, girls in the age group 10-12 years old showed no change in width ratio in 8 out of 10 observed cases. The other two cases showed a decrease in width ratio with growth. Neither group appeared to show any correlation between degree of alteration of width ratio and the amount of overall length growth of the foot.

Growth period from 7 to 14 years. Only three cases out of 14 showed a noticeable change in width ratio, one increasing

from 60 to 68, the other two decreasing by similar amounts. Again, no correlation between age or amount of foot length growth and change in width ratio could be established. At 7 years old, the mean value for width ratio was 63.7, while at 14 years it was 64.0. This difference in mean values is not statistically significant ($t = 0.19$; $d.f. = 26$).

Growth period from 14 to 21 years. Only two cases out of 25 showed noticeable changes in width ratio, both showing increases in value of over 5 units. The mean value for width ratio for the adolescent group (14 years old) was 63.3, while that for a mature group was 63.7. The difference between these means is not significant ($t = 0.41$; $d.f. = 48$).

It was observed that feet of the same length with a common width ratio always had identical heel and joint widths though theoretically this need not be so; e.g., if, from the records, feet 8.3 inches long and having a width ratio of 67 were selected, they could theoretically have heel widths and joint widths of 1.8 and 2.7 or 2.2 and 3.3 inches respectively (thus both showing width ratios of 67); but in actual fact they were consistently found to have heel and joint widths of 2.0 and 3.0 inches respectively.

This finding may be expressed as follows: Though feet of the same length may have a number of widely different heel widths, the variation amounting to as much as 0.5 inches (Hill and Isherwood, '49b), each heel width will be closely associated with a specific and limited range of joint widths. There therefore exists a close multiple correlation between foot length, heel width and joint width, and foot length coupled with the heel width/joint width ratio appear to characterize the plantar shape.

Finally, as the large majority of these girls' feet showed no real alteration in width ratio with growth over a number of years, it would appear that heel and joint width growth of the foot are proportional, and that the spread of the foot, as defined by these two linear dimensions, does not alter between the ages of 7 and 21.

2. *Foot breadth index (joint width/total length)*

During 18 months growth from approximately 10 to 12 years old, 8 of the 10 observed cases showed an increase in foot breadth index, i.e., a widening of the forepart of the foot relative to its length, while only two cases (incidentally twin sisters) showed a decrease in this index. Although in all these cases the degree of change in the index was small, never exceeding three units, this represents an 8 to 10% change, which far exceeds the likely experimental error in measurements taken, and it can be concluded that the width/length proportions of these particular feet did change during this period of growth. The average increase in foot length for these feet during 18 months was 0.6 inches.

Growth from 7 to 14 years. The general trend was a slight increase in the value of the foot breadth index, with only three cases out of 14 showing slight decreases. The changes in value were, however, not large enough to be meaningful. At 7 years old the mean index value was 36.1, while at 14 years it was 37.0; this is not statistically significant ($t=1.46$; $d.f.=26$).

Growth from 14 to 21 years. Again the general trend was towards an increase in foot breadth index with age, only one case out of 25 showing a slight decrease. The mean value for the index at 14 (adolescent group) was 37.4, while at 21 years (maturity) it was 38.7. When tested statistically, this increase is significant ($t=2.45$; $d.f.=48$; $p=2\%$).

There would thus appear to be a distinct general trend towards slight broadening of the forepart of the foot relative to its length with increasing age. This was evident in all three periods of growth under consideration in the present study.

In this connection it is of interest to compare Wartenweiler's study, wherein he showed that foot breadth index for both males and females remained virtually constant at 38-39 from the ages of 7 to 18 years.

3. *Ball length index (heel to ball/sole length)*

In the 18 months' growth between 10 and 12 years of age, the proportion of ball length to length of the sole of the foot

remained fairly constant, but the index in 10 individually observed feet showed changes of one to three units. This indicates that there is a change in the proportion of great toe length or heel to ball length during this particular period of growth but the group was too small to establish definite trends. The mean value for ball length index in this age group was 71.

Growth period from 7 to 14 years. The mean values for ball length index for the group were 72.9 at 7 years and 71.5 at 14 years old. Statistically this difference is significant ($t = 2.98$; $d.f. = 26$; $p = < 1\%$). In this group, 12 out of the 14 observed cases showed a decrease in ball length index with increasing age, the decrease in the value being of the order of 3%, which is more than would be accounted for by experimental error. There is thus little doubt that the heel to ball proportion decreases in the growing foot.

Growth period from 14 to 21 years. Of the 25 observed cases, 16 showed decreases in ball length index of the order of 3%. The mean value of the index for the 13-14-year-old group was 72.2 while for the mature group it was 71.3. Statistically this difference is significant ($t = 2.06$; $d.f. 48$; $p = 5\%$).

It may be concluded that there is a definite trend towards a decreased ball length index in the growing foot from childhood to maturity, i.e., the toes tend to become proportionately longer in the adult foot.

4. *Outside joint index* (heel to outer joint/sole length)

This index should be considered in relation to the ball length index, as the two indices together reflect changes in the slope of the treadline of the foot.

During the growth period from 10 to 12 years, 7 out of 10 observed cases showed an increase in outside joint index, while three showed a decrease. The change in index value was however too small to be meaningful. The mean value for the index at these ages was 63.

For those feet representing growth between 7 years and 14 years of age, the mean value for the index was 64.7, for the

younger feet, and 64.4 for the older feet; while for feet changing from 14 to 21 years of age the mean value at adolescence was 63.6, and 63.7 at maturity. In the 7 to 14 year growth period, 8 out of 14 cases showed a slight but insignificant decrease in index. During the 14 to 21-year-old growth period 15 cases out of 25 observed showed a definite decrease in index, but the differences were not sufficiently greater than experimental error to be of importance.

There would therefore appear to be no significant change in the relative position of the outside joint during foot growth at the ages studied. As it has been shown in the previous section that the relative position of the ball joint tends to become shorter with age, this would suggest that the angle of the treadline becomes squarer in the older foot.

5. Instep index (instep height/total foot length)

During 18 months growth (approximately the 10 to 12 year period), 7 out of 10 observed cases showed decreases in instep index, of the order of 8 to 10% which is rather more than experimental error.

Growth period from 7 to 14 years. Eleven cases out of 14 showed increases in instep index, the mean value changing from 26.7 at 7 to 28.2 at 14 years old, which is significant ($t = 2.03$; $d.f. = 26$; $p = > 5\%$).

Growth period from 14 to 21 years. Twenty-four out of 25 cases showed significant increases in instep index, many of them of the order of 15–20%, which is far in excess of possible experimental error. The mean index value at 14 was 25.17, and at 21 years was 28.26. ($t = 8.04$; $d.f. = 48$; $p = < 0.1\%$).

There would thus appear to be a very definite increase in the height of the instep relative to foot length as the foot matures and it is highly probable that this can be related to the increased tendency for older girls to wear higher heeled shoes—it should be remembered that as heel height increases in a shoe, it is customary to give the last more curvature in the waist region, and this would tend to arch the foot and raise the

instep. This arching apparently soon persists in the foot even when it is at rest with the heel flat.

6. *Arch index (arch height/total foot length)*

It is pertinent, in view of the foregoing section, to consider what happens to the arch height of the foot, as defined by the prominence of the navicular bone.

During the 18 months growth period between 10 and 12 years old, 8 cases out of 10 showed a decreased arch index, and two showed increases. The decreases in index were appreciable, of the order of 10-20%.

Growth period from 7 to 14 years. Six cases showed an increased index, while 7 cases showed a decrease. One case showed no change. The changes in index were under 10%, which is less than the possible experimental error in the case of arch height measurement. The mean value for arch index at 7 years of age was 18.9, and at 14 years was still 18.9.

Growth period from 14 to 21 years. Of the 25 cases, 21 showed increases, while only 4 cases showed decreases in arch index. The majority of the increases were of the order of 12 to 20%, which is considered meaningful. The mean value for arch index changed from 16.9 at 14 years to 18.6 at 21 years old ($t=3.0$; $d.f.=48$; $p=0.1\%$).

Thus it appears that the increase in instep index is accompanied by an increase in arch height index as the foot matures, and this could conceivably also be related to the habit of wearing higher heeled shoes.

7. *Joint girth index (joint girth/total length)*

During the 18-month period between the ages 10 and 12, 9 of the observed 10 cases showed an increase in joint girth index, while one showed a decrease. The increases were of the order of 5 to 10%, which is far in excess of possible experimental error. Thus, during this growth period, the foot becomes proportionately larger in joint girth. It has already been shown to increase in joint width relative to its length.

Growth period from 7 to 14 years. All the 39 observed cases, without exception, showed increases in joint girth index. Over the growth period from 7 to 14 years old, the mean value for the joint index increased from 89.5 at 7 years to 94.0 at 14 years, which is significantly greater than experimental error ($t=3.48$; $d.f.=26$; $p=<1\%$).

Growth period from 14 to 21 years. All 25 observed cases showed substantial increases in joint girth index. At 14 years the mean index value was 91.6, while at 21 it was 96.3 ($t=4.60$; $d.f.=48$; $p=0.1\%$).

These results indicate a consistent and definite increased girth growth relative to length as the foot matures. This has an immediate practical significance, as it means that the girth/length proportions of shoes should be varied according to the age of the person for whom they are intended. Many adolescent children have feet that are long for their age, but it is incorrect to fit them with adult shoes, which would be too large in the girth. They should be provided with shoes designed specifically for young feet, and if need be, the youths' or maids' shoe size range should be extended to cater for the above-average length foot.

This study confirms the fact that the female foot continues to increase in girth after the age of 13-14 even though it frequently ceases length growth at this stage.

8. *Girth index (joint girth/instep girth)*

During the 18-month interval between 10 and 12 years, 8 of the 10 cases showed an increase in girth index, but only two of these appeared important. Two other cases showed no alteration in index.

Growth period from 7 to 14 years. Thirteen of the 14 observed cases showed increases in the girth index, and one case only showed a small decrease. The increases found were considered large enough to be important. At 7 years the index mean value was 96.8, while at 14 years it was 99.2 ($t=2.42$; $d.f.=26$; $p=<5\%$).

Growth period from 14 to 21 years. Eleven cases of the 25 studied showed increased indices, 12 showed decreases (which were of a bigger order than the increases), and two cases showed no change in the index. The index means were 99.0 at 14 years and 98.8 at 21 years old, which is not statistically significant.

It would appear, therefore, that in the younger growing foot, there is a distinct tendency for the joint girth to grow at a greater rate than the instep girth, but that after adolescence the two girth growths proceed equally, with the instep tending to become proportionately larger than the joint.

The actual value of this index is of practical interest; the mean value was shown to be 96.8 at 7 years and 99 for feet of 14 years and over, which means that in shoes for younger children the instep region should provide greater girth than in the joint region, while for older groups and adults the two girths are virtually identical. The shoe industry has a feature in its lasts known as "rise," which indicates that the instep girth is greater than the joint girth, and most lasts incorporate "rise" of the order of a quarter of an inch. The present study indicates that the relative proportions of joint and instep girths in lasts for different age groups might be more carefully studied with advantage.

9. 5th metatarsal index (heel to 5th met. base/total foot length)

During growth from 10 to 12 years old, 7 of the observed 10 cases showed increases in this index, but the changes were not greater than could be accounted for by experimental error.

Growth from 7 to 14 years. All 14 cases observed showed a decrease in the index with increasing age, and only one case could be attributed to possible experimental error. At 7 years the index mean value was 41.7 while at 14 years it fell to 38.0 ($t = 5.56$; $d.f. = 26$; $p = 0.1\%$).

Growth period from 14 to 21 years. Here 22 cases of the 25 observed showed decreases in the index value, with most of

them definitely larger than experimental error. At 14 years the index mean value was 40, while at 21 years it fell to 38.1 ($t = 2.71$; $d.f. = 48$; $p = 1\%$).

It appears then that as age increases the distance of the 5th metatarsal base from the back of the heel represents a smaller proportion of the total foot length. In practice it is doubtful whether this change in proportion can be accurately catered for in footwear, since the variation in the 5th metatarsal base position in feet of the same length is too great to enable last makers to accommodate this bony protuberance with precision. Nevertheless, in some lasts, a deliberate fullness is provided in the cuboid region, and it is of value to know the correct location of the 5th metatarsal base prominence and how this varies with age.

SUMMARY AND CONCLUSIONS

Measurements made on the feet of 41 girls of school-going age have been described, and have been analyzed by means of 9 defined indices so as to show the changes, if any, that occur in certain proportions of the female foot during growth. The study is more comprehensive than is usually found in respect of the human foot in anthropological literature.

By recording measurements of these girls' feet first in 1947, and again in 1949, and finally in 1956, the development of the foot has been traced after an initial period of 18 months growth, and again after a further $7\frac{1}{2}$ years growth. The data have been divided according to whether the subjects changed from childhood to early adolescence or from adolescence to maturity, and differences in foot growth for these two growth stages have been investigated.

The main findings of interest were as follows:

1. There appeared to be no significant change in the foot width ratio (heel width to joint width) with increasing age, and the spread of the foot, as defined by these two dimensions, did not alter in individual feet between the ages of 7 and 21.
2. Length of foot together with the width ratio appeared to characterize plantar foot shape, i.e., a foot of given length

and given width ratio had a predictable heel width (and hence joint width).

3. Feet showed a definite trend to broaden across the forepart, in relation to their length, with increasing age. This was particularly noticeable during the adolescence to maturity growth period, and may be a result of the general increase in body weight.

4. With increasing age there was significant increase in the proportionate length of the great toe, i.e., the heel to ball proportions of the growing foot decreased with age. A similar change in the relationship of heel to outer (5th metatarsal) joint length to overall foot length was not evident from the results, suggesting that the angle of the joint or tread line changed with age.

5. The most striking change in foot proportions occurred in the instep region, the height of the instep becoming significantly larger relative to the foot length with increase in age. This could possibly be associated with the tendency to wear high-heeled footwear.

6. This alteration in instep proportions was accompanied by a positive change in the height of the navicular arch relative to foot length.

7. There was a consistent and significant increase in the proportion of joint girth to foot length with age. The older foot was fuller in girth for its length than was the younger foot. This has practical implications in the design of footwear for specific age groups.

8. The relationship between joint and instep girths varied with age, the former being less than the latter in younger feet, but this relationship tending to reverse in older feet.

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BOOK REVIEW

LES NÉANDERTHALIENS: ANATOMIE, PHYSIOLOGIE, COMPARISONS. By Étienne Patte, 559 pp., Masson et Cie, 5,000 fr. Paris, 1955 (actually printed in 1956).

L'ENFANT NÉANDERTHALIEN DU PECHE DE L'AZÉ. By Étienne Patte, 234 pp., 13 figures and 8 pls., 2,500 fr. Masson et Cie, Paris, 1957.

Careful study of these two impressive volumes by the Dean of the Faculty of Sciences at Poitiers, produces mixed emotions: Gratefulness for a new research approach to the Neanderthals and for details about previously undescribed specimens; disappointment that the author did not re-examine the original La Chapelle-aux-Saints skeleton, but simply quotes Boule's descriptions thereof; and annoyance that the author's description of the Pech de l'Azé infant is buried in a mass of comparative data, much of which is irrelevant and possibly outmoded. To understand these reactions let us look at the books separately.

According to the publisher's announcement, the earlier and larger work "replaces the study of Marcellin Boule on the Man of La Chapelle-aux-Saints, now unavailable [published in 1911-13] and less detailed. No fact of Boule's book has been omitted." This is indeed the case; usually each section begins with a summary of Boule's findings or a direct quotation, and then proceeds with comparative data. The author never states that he has looked at the original. Obviously, then, if Boule overlooked or misinterpreted some detail, Patte is unlikely to have included or corrected this detail, unless someone had discussed it in the literature. For example, Boule gives no details of the osteo-arthritis of the spine, and therefore neither does Patte. As a matter of fact, he does not even include Boule's fine illustrations.

Even in the matter of comparative data on the Neanderthals Patte does not go much beyond Boule, who relied mainly on the first Neanderthal, Gibraltar, Spy and La Ferrassie. Patte does refer occasionally to La Quina (published in 1923), but he ignores the significant recent finds of Mount Carmel, Saccopastore, Monte Circeo, etc. The

reason for not bringing this study fully up-to-date in this regard is explained only as part of the justification for using La Chapelle-aux-Saints as the type specimen:

I have compared La Chapelle with other "Neanderthals" while continuing to give to this term a meaning as strict as possible. In dealing with such a homogeneous type it would be truly awkward to stump ("estomper," i.e., to shade) the contours; it is partly because of this that I refuse to combine him with the man of Steinheim and those of Palestine. For the same reason I would qualify as "Neanderthaloids" the men of Broken Hill and of Ngandong, who possess in common with him some strongly marked characters, it is true, but too few. (p. 5, free translation)

Although he limits his comparisons to certain classic Neanderthals, Patte does not hesitate to express his opinion on certain broad interpretative matters. Thus he has the following to say about Neanderthal posture:

It is certain that to a different morphology corresponds an often different physiology; but the facts are so complex and the variations such today that it is wrong to attribute to Neanderthal a posture ("allure") bestial and different from that of modern man. It was not a Parisian gait ("demarche"), but then there were no Parisians in existence. (p. 452, free translation)

Also, he has the following to say on the place of Neanderthals in human evolution:

It is practically certain that there never existed a Neanderthaloid type forming the perfectly intermediate morphological link between Pithecanthropus and *Homo sapiens*, or better between the simian ancestor and present Man. Mutations must have occurred, introducing here something progressive, there something else; the representatives, thus favored in one way or another, would have crossed with each other or with others less favored. It is only little by little, in spite of all the brewing, all the mixing, that the archaic characters have totally or almost totally disappeared and that the modern types have become almost fixed. . . (p. 512, free translation)

If such statements reflect personal opinion more than the consensus of the Neanderthal literature, at least they are backed up by a large bibliography concerned with modern man and the anthropoids. I estimate that the bibliography, which fills 32 pages, contains around 800 items. Some of these references seem to me to be of dubious quality, but on the whole they constitute a useful assemblage.

In spite of such criticisms, *Les Néanderthaliens* seems to be unique in that it is arranged by anatomical features around La Chapelle as a type. Thus, for example, if one wishes to learn about the mastoid

process in Neanderthals, the data which the author has elected to present are summarized in one place. Undoubtedly, therefore, the book is a useful, if limited, reference work. Perhaps it is like crying for the moon to wish that the author had, in addition, restudied La Chapelle and developed some new illustrations.

The second book is only half the size of the first, but it gives details of two hitherto undescribed Neanderthal infants: Pech de l'Azé (pp. 1-196) and Chateauneuf-sur-Charente (pp. 197-226). The first of these infants consists of an imperfect skull and lower jaw; the second consists of the anterior part of the left side of the mandible (I have not found concise statements to this effect in the text, but this is what the pictures show). Both specimens are between two and three years of age. The author says that Denis Peyrony found the Pech de l'Azé skull, but not when (1919, according to the publisher's announcement; 1909, according to Vallois in the *Catalogue des Hommes Fossiles*). Also, he does not say how well it was restored by Boule or where it is now preserved (Musée de l'Homme in Paris, according to Vallois).

The Chateauneuf-sur-Charente mandible, on the other hand, was not included, at least under this name, in the *Catalogue des Hommes Fossiles*, and now the title of the present book does not indicate its presence, so it can be regarded as lost bibliographically. This specimen was found by G. Chauvet on April 1, 1908, and presumably is now in the Musée de l'Homme.

With these historical details out of the way we can return to the criticism expressed at the beginning, that the description of the Pech de l'Azé infant (and likewise that of its companion) is buried in comparative data. On page 84, for example, under the heading of sutures, begins two pages of text dealing with the relative position of asterion. Here many opinions regarding this feature are given for Neanderthals, anthropoids and modern man, but not until the very last sentence is there a mention of Pech de l'Azé: "Mais il est remarquable que l'astérion occupe sur le crâne du Pech de l'Azé une situation absolument comparable à celle attribuée à celui de l'enfant de Gibraltar." In this case not only is the information buried, but once uncovered it cannot be readily used. Unfortunately this is not an isolated example of the author's style. Since infant remains are being described, it is difficult to understand the necessity for so much comparative data on adults, both human and anthropoid. In the places where the author uses these data to speculate on the hypothetical adult stage, had the infant lived to maturity, the exercise can only be regarded as futile. Also the sources are not always up-to-date (On the pterion in anthropoids, for example: Selenka, 1898; Abel, '31).

I have other complaints about this book. The plates are so crowded that no view of the skull or lower jaw exceeds three inches in greatest dimension. In some views the skull is oriented on the Broca plane, in others in the Frankfort plane. Plate legends, all too brief, are inconveniently placed on a separate page. And finally, the bibliography contains only references not published in *Les Néanderthaliens*!

In spite of these defects the book does contain much welcome information.

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BOOK REVIEW

MORPHOLOGICAL INTEGRATION. By Everett C. Olson and Robert C. Miller. Pp. xvi + 317 \$10.00. University of Chicago Press, 1958.

We are in an advancing period of analyzing morphology, following the stage defined by comparative description, by the study of variation in single characters (in anthropology, cf. Hrdlicka), and by finding parameters (mean, standard deviation) for a single measurement. Pearson and Boas were long ago interested in the relations between characters, without having a very wide influence. Later, Huxley and D'Arcy Thomson dealt with relative growth and transformations. Only recently has there appeared the search for a clearer definition of the units of study in evolution. Anatomists having been endeavoring to build these up from direct observations. LeGros Clark has been emphasizing the "total morphological pattern" and in anthropology Washburn has been suggesting animal experimentation as an avenue to interpretation. Using the general idea of multivariate analysis, Olson and Miller add to this a formal, quantitative method based on intensive measurement.

Their object is to abstract numerical expressions of morphological integration, a term which means what the reader might suppose. They wish not only to specify the units of integration (the "morphological patterns" found in an organism) but to measure the intensity of the integration, both within such units, and between them, as they merge in the whole functioning animal. They believe not only that this approach will indicate the entities to be studied in evolution, but also that the intensity of integration existing at any one time in a phylogenetic line is a matter of significance for evolution as well.

They have carried out an impressive number of such analyses, on both living and extinct forms, confining themselves to the skeleton or parts thereof for the sake of keeping common ground between neozoology and paleontology. They assume that the integration of pattern, or system, results partly from common developmental causes and partly from common responses to, or roles in, function. In a study of the frog skeleton (*R. pipiens*) they selected measures related respectively to the forelimb locomotor system, the hindlimb locomotor system, axial movements, head orientation and jaw movement. At the high-

est levels of integration, all the groupings or systems named are distinct from one another, the fore and hindlimb measures being most strongly integrated or correlated within their groups, and those connected with jaw movement only slightly. At lower levels, the forelimb system becomes related to the hindlimb system in a general locomotor grouping, and forelimb also becomes related to head orientation and axial structures, with which the hindlimb system is only very weakly integrated. These results are specific for the frog, of course. Many other suggestive findings crop out of all this preliminary work, which is meant to be more a development of method than anything else. For example, a fossil amphibian's dermal skull elements showed low correlations, suggesting a considerable latitude in single elements within the whole developmental plan in the absence of control by functional demands, which seems to echo phenomena of variation in the human braincase.

The method is as follows. The authors use long lists of measures: 50 on the frog skeleton, 45 on the squirrel skull and 83 on the cheek teeth of the night monkey, *Aotus*. Measures are grouped in two different ways. They are first selected and arranged according to qualitative biological considerations — total morphological patterns. They are grouped again from correlations among the measurements, by routines which are the essential contribution of the authors. The object is to test the correspondence of the mathematically derived groupings (and their degree of integration) against the logically established groups, with the final aim of using the quantitative method on paleontological material which is not amenable to neozoological experimentation and analysis. The routines consist in finding the "bonds" and groups which can be established between measures at different levels of r . After their thorough testing, the authors believe they have "developed tools more sensitive than any hitherto available to the paleontologist" in investigating cause and mechanism. They have certainly opened up the field.

A few mild criticisms. The authors explain themselves so rigorously as to make their method seem more complex than it is; there is actually nothing more essentially mathematical in it than the calculation of r and establishing confidence limits therefore. Also, no real consideration is given to previous allied work by non-paleontologists: Burt, Thomson, Thurstone and Holzinger, for example, do not appear in the bibliography, though they have dealt with similar problems of quantitative analysis. Whether all this is called multivariate analysis, or factor, or cluster, or pattern, analysis, it comes down to taking advantage of the possibilities of covariance, the coefficient of correlation being the essential powerful weapon, as the authors make

clear. We seem to be in a state where standardized and simplified methods of exploiting correlation have not yet appeared, so that Olson and Miller have been able to work in relative isolation from those in other fields. It seems like a case of independent invention, which always suggests that the need for the invention in question exists in various quarters.

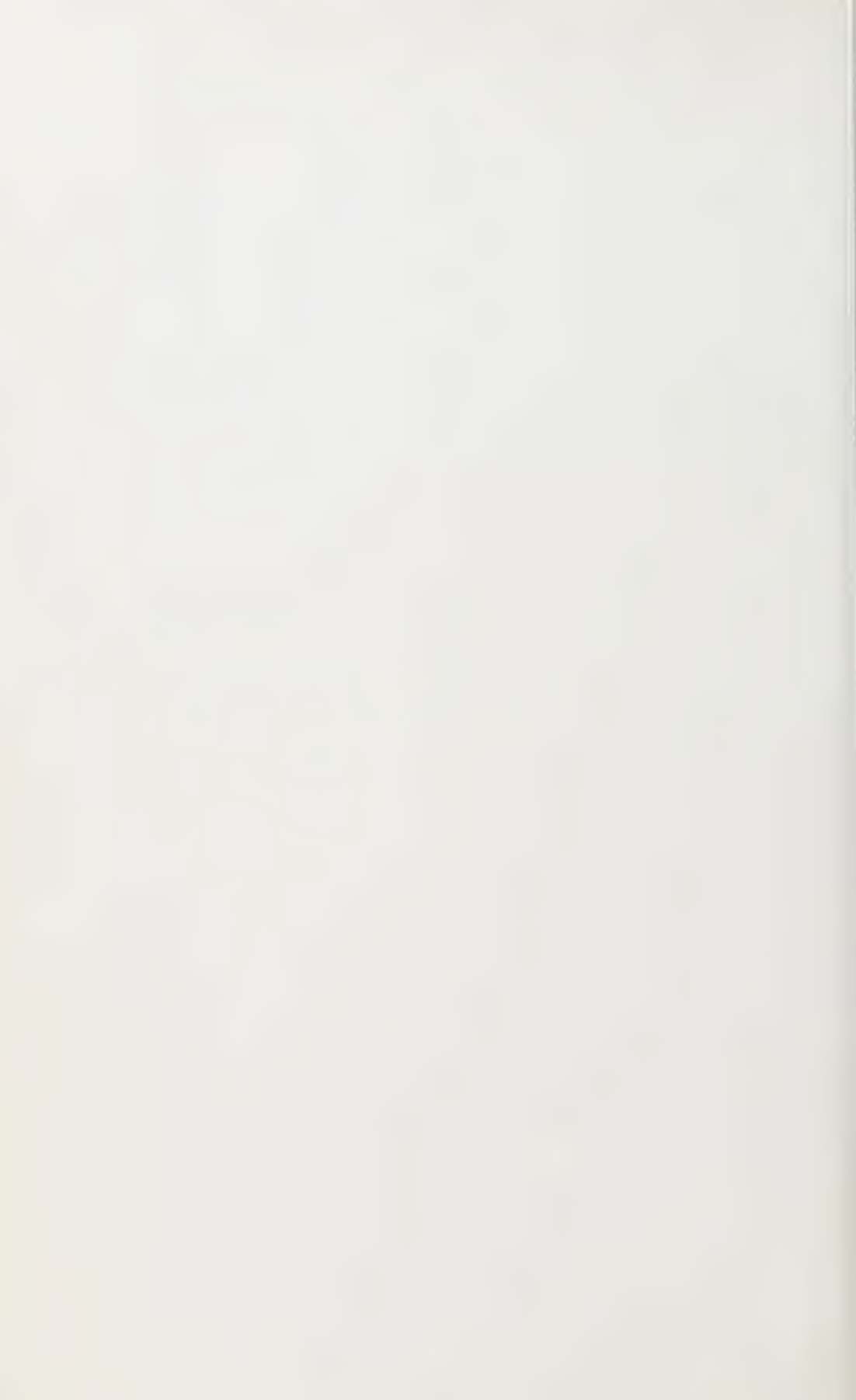
Other quibbles. The raw measurements of the several studies are provided in tables in the appendix, but the correlations, from which the authors work, are not given, except in a few cases where used in examples; this is most unfortunate. Furthermore, the valuable measurements on *Aotus* teeth, in table 111, are not identified by the same numbering system as is used in the text, so that the table is useless to others.¹ Finally, — and not alone among University of Chicago Press hard cover books — the volume is pretty expensive.

Nevertheless it is a valuable book. Olson and Miller hope they will have stimulated others to use their approach, something highly likely to happen. They deal with nothing closer to man than *Aotus*, but it is the method which counts. They point out the advantages it provides for paleontologists, who lack certain techniques available to neozoologists, and the same can be said for anthropologists, man being notoriously not an experimental animal and therefore well suited to study by secondary methods like multivariate (correlation) analysis. Their discussion of general problems of morphology, particularly in their first chapter, is excellent and well expressed. Any physical anthropologist who delays reading the book is only putting off some basic homework.

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¹Dr. Miller tells me that the sequence of measurements in table 111 is the same as that in figure 55, disregarding the breaks in the sequence of numbers used in the latter.



BOOK REVIEW

DARWIN'S CENTURY: EVOLUTION AND THE MEN WHO DISCOVERED IT. By Loren Eiseley. xvii + 378 pp., \$5.00. Doubleday and Company, 1958.

Charles Darwin, M.A., L.L.D., F.R.S., voyager, naturalist, evolutionist and (later) recluse at Kent, is no easy man to write about. Though his contributions are prodigious and his correspondence was wide, rather little of his private life is known. To place Darwin in time and space, a biographer needs a historian's knowledge of 19th-century England, a naturalist's love of natural history, and an evolutionist's background in evolution. West was not quite successful, Sears proved inadequate for the task, and Irvine could never warm to a subject so foreign to his own interests. Loren Eiseley holds the winning combination, including a 19th-century literary style, admirably suited both to the time and to the subject.

This book, to be sure, is not just about Charles Darwin. It has a prologue (5 chapters, 140 pages) leading up to Darwin, and an epilogue (8 chapters, 120 pages) mostly leading from Darwin. It includes Eiseley's "Reception of the First Missing Links," a long, fine chapter no anthropologist should be allowed to miss. Wallace figures too, that remarkable figure whose later days were darkened by metaphysical leanings. But the ghost of Darwin stalks the pages, beetle-browed, bearded (as in his later years) stronger now that natural selection has been put upon a genetical basis.

This is one book that cannot be reviewed by searching for typos, or gleefully discovering authorities that the author missed. Nor can one complain about the index, which is a splendid one, or the details of manufacture. Even the end-paper pictures of Hooker, Darwin, Huxley and Lyell are tastefully reproduced, in a form resembling collotype; considerable artistry is evident in the chapter headings. Imaginative collaboration between author and publisher is apparent. But what a job it must have been to read the page proofs!

Judging from other reviews in which not a single *caveat* was sounded, the present reviewer is hardly alone in his admiration for *Darwin's Century*. Moreover, this splendid book is not only suited to the interest of the aficionado, but to the student as well. Where general education courses are given, *Darwin's Century* (along with

the *Descent*, and relevant portions of the *Origin*) can be included in the basic readings. In no other place is the story of Patrick Mathew and his little essay on Naval Timbers presented quite so well.

There are now, of course, a host of books signaling the Darwin Centennial. We may anticipate several that will concentrate on Darwin's psyche, in approved pseudo-psychoanalytical literary fashion. But the importance of Darwin lies less in the early demise of his mother, the bullying of his extraordinarily obese father, the relationships with his sickly older brother, Erasmus, or his marriage to cousin Emma Wedgewood, than in his contributions to the world of knowledge and thought. These, Loren Eiseley has detailed in scholarly fashion, thoroughly, and in a most enjoyable and literate style.

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BOOK REVIEW

SOVETSKAIA ANTROPOLOGIIA. The appearance of a new journal in the field of physical anthropology is an event of major importance that should not pass unnoticed in these pages. For two decades since the demise of the former *Antropologicheskii Zhurnal* in 1937, Soviet physical anthropologists have lacked a publication medium devoted to their discipline. The results of their work have been scattered among journals and serials in other fields, chiefly ethnography and archaeology, with a resultant emphasis upon materials and problems of historical significance. The great expansion of field work in recent years, the diversification of research in this and related fields, and the revived contacts with foreign colleagues have all led to growing interest in improving methodology and in exploring new problems and new avenues of approach which, it is felt, may prove more significant than those hitherto the center of attention. This trend has at last found expression in a new quarterly, *Sovetskaia Antropologiia* ("Soviet Physical Anthropology"), published by the Institute of Anthropology at Moscow State University, the first issues appearing in 1958 although dated 1957. Editor-in-chief is M. A. Gremiatskii, assisted by a board composed of G. F. Debets, M. V. Ignat'ev, M. F. Nesturkh, I. A. Roginskii and V. P. Iakimov — all prominent figures in the discipline.

The scope of the journal is stated to include anthropogenesis, primatology, palaeoanthropology, racial studies, human morphology, methodology of anthropometric and anthroposcopic research, and anthropological standardization in the realm of industry. It is aimed not only at physical anthropologists, but at all scientists in adjacent fields who are interested in man from a biological viewpoint. Although dedicated to expounding the progress of thought and reporting the research of Soviet physical anthropology, it will also follow developments in the discipline everywhere in the world.

Both the nature of the new journal and the current interests of our Soviet colleagues are well reflected in the contents of the first issue of 144 pages. Some representative titles include: "Forty Years of Soviet Physical Anthropology" (G. F. Debets — with an extensive bibliography), "Darwin and the Problem of Anthropogenesis" (I. A. Roginskii), "Fossil Apes in the Territory of the U.S.S.R." (M. A. Gremiatskii), "Proportions of the Body as a Racial-Taxonomic

Criterion" (P. N. Bashkirov), "Biometric Problems in Physical Anthropology" (M. V. Ignat'ev), "Physical Anthropology and the Tasks of Light Industry in the U.S.S.R." (P. I. Zenkevich), "Physical Anthropology in Hungary during the Past Five Years" (Tibor Tot), "Latest Palaeoanthropological Discoveries in Africa" (M. I. Uryson), "List of Dissertations in Physical Anthropology at Moscow State University, 1940-1957."

The present writer has ascertained that subscriptions to *Sovetskaia Antropologiia* may be entered through Collet's Russian Bookshop, 45 Museum Street, London W. C. 1. (\$6.02)

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SKELETAL MATURATION; AN APPRAISAL OF CONCEPT AND METHOD¹

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ONE FIGURE

During recent years it has been the practice to assess the maturity of the skeleton, clinically and in developmental studies. The purpose of this paper is to discuss the usefulness of the procedure and to refer to methods of its assessment.

INTRODUCTION

Anatomical considerations of skeletal development are important to this discussion. Growth, as increase in length of the human skeleton, occurs by proliferation of cartilage cells in cartilaginous areas, and this process is continuous from early fetal life. As a sequential process, after vascular penetration of primary and secondary centers, the process of ossification of the cartilaginous areas starts by deposition of osteoid tissue. When ossification is completed bone growth has ceased.

It is not known what determines the appearance of primary and secondary centers. Felts ('57a, '57b) in transplantation experiments has shown that cartilage alone has versatile properties in this respect. Clearly this timing and the subsequent process of ossification may have a great bearing on the ultimate size of a bone. The problem is to examine whether the process of cartilaginous proliferation (chondroplasia) is independent of the process of bone formation (osteogenesis) in

¹ Based on a paper read at the 26th annual meeting of the American Association of Physical Anthropologists.

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the human. It is the latter which has been termed skeletal maturation.

It is apparent that in health, in the growing child, these two processes are intimately linked and dissociation does not occur though the relative *rates* may differ. But if dissociation does occur, what may be its effect on the size of the child? Suppose osteogenesis did (and could) occur, very rapidly while chondroplasia proceeded normally in a particular bone, then the potential growth-life of a particular bone would be diminished and that bone would be finally stunted. If the reverse were true, the bone would be finally enlarged. Considerable independence apparently *can* exist between, for instance, height and skeletal maturation in the first 5 years of life (Elgenmark, '46). Clearly in studying normal and abnormal growth of the child, to examine this question is important for it may be fundamental.

It has been suggested that chondroplasia and osteogenesis may each be controlled by different endocrine systems, (Acheson, '56) for basic work on the rat (Ray, '50; Becks, '50; Evans and Simpson, '54) suggests that there may be some basis for this theory in that animal. In the human this is difficult to accept for in hypo-thyroidism (cretinism) in children there is dwarfing and retardation of skeletal maturation. If only the osteogenetic process were slowed, then in theory the cretin has more time to proliferate cartilage and hence should be taller than average. Further, the hyperthyroid child is usually advanced in osteogenesis ("bone age") and is taller than average for his age, (Warkany, '50). Again, in pituitary dwarfism the length of the bones is diminished and so is the rate of appearance of epiphyseal centers. (Warkany, '50.) In hemi-hypertrophy (Debré and Lelong, '52) the side of the body which contains the longer (and larger) limbs, also has an advanced rate of ossification center appearance compared to the smaller side. So far, then, in health and certain diseases these processes appear to be linked and affected equally. This is not surprising and, of course, does not preclude endocrine control, but almost certainly precludes such suggested simple

division of controlling factors. Wilkins ('50) maintains that growth in stature (chondroplasia) and osseous maturation (osteogenesis) are both to some extent under the control of the thyroid gland by the hormone thyro-globuline; but there is a regulating effect of this hormone on the anterior pituitary, and that this gland itself produces a thyro-tropic hormone which acts on the thyroid.

There are further important hormones to be mentioned, namely the androgens: In the adreno-genital syndrome one of the features is that hyperactivity by the adrenal cortex results in earlier than average appearance of epiphyseal centers and closure and thus the child prematurely is unable to grow in length further; he is likely to finish up shorter than average on reaching maturity. However, before complete skeletal maturity is reached he is always taller than average for his age. Because chondroplasia does not appear to compensate by speeding up or be equally affected the potential growth period is diminished and diminution in final stature results. Here, the two processes do not appear to be affected equally. Sobel and her co-workers (Sobel et al., '56) on treating small children with methyl testosterone concluded that this agent, while accelerating both linear growth and skeletal maturity, the increase in the latter relatively exceeded the former and thus acted as a final growth stunter.

Adult stature is determined by the speed of linear growth and by the duration, which is a function of skeletal maturity. Bayley ('46, '52) theorized that since final stature and complete skeletal maturity are attained at the same time, after examination of large samples of children followed longitudinally, it should be possible to predict the adult height. There was a high correlation between "skeletal age" (i.e., osteogenesis) and the proportion of final adult stature that had been reached when an x-ray film was taken. This showed the close relationship between growth in size and skeletal maturation, and the very real possibility of predicting adult height. She (Bayley, '56) has recently found on further study that the estimated proportion of final adult height achieved from the

study of the x-ray film, and the proportion of height actually achieved were not necessarily the same.

The effect of illness on the growing child serves as another example of the problems discussed. Hewitt, Westropp and Acheson ('55) presented data showing that children in the first 5 years of life serially followed suffering from illnesses grew less in any one year over the whole of this period, compared to children who were not ill. They did not, apparently, "make-up" this deficit during the period studied. These same children had their skeletal maturity assessed by a method (the Oxford Method) which will be described later, and there was no similar slowing nor any difference between the two groups. If this is so it is clearly very important, for dissociation between chondroplasia and osteogenesis had taken place and if nothing occurred later in life to alter this effect, then the ill children would be shorter as adults than if they had had no illnesses. Falkner ('59) in a similar study (on the first three years of life) but with more frequent examinations, has shown that slowing of growth certainly occurs amongst the sick children (of both sexes) but only at an age directly related to the timing of the illnesses, and that in the first three years of life this deficit is not made up. Skeletal maturity, on the other hand, was concomittantly slowed significantly, but only in the boys. Interestingly enough it has been indicated that boys' skeletal maturation is more susceptible to vicissitudes than girls. (Todd, '37; Francis, '39, '40; Acheson and Hewitt, '54; Acheson, '54, '56.) Remembering that boys are delayed compared to girls in skeletal maturity, perhaps here the timing of the illness in relation to the *state* of skeletal maturity is important. This leads one to suppose that there may be, then, a possibility that the two processes under discussion can be dissociated under certain circumstances.

This is not the place to discuss whether there was, or was not a concurrent slowing of skeletal maturity but it does make us question methods of assessment. It leads, too, to a fundamental point: to carry out any investigation into this matter we must be able to measure the variables. Height is clearly

an excellent indicator of chondroplasia and can be measured accurately. But osteogenesis is extremely difficult to measure and a discussion on method must follow.

Method of assessment

All the methods thus far have been based on radiological pictures of some area, or areas, of the skeleton: Cartilage is highly permeable to x-rays, whereas bone is relatively impermeable and thus osteogenesis can be observed with ease. Measurement of the size and density of bone images has been proposed (examples: Carter, '26; Sawtell, '29) but is found to be impractical for it is very time-consuming and not accurate. Radiography of all the joints on one side of the body (Sontag and Lipford, '43; Lurie, Levy and Lurie, '43) and the counting of ossified centers has the advantage that it does not assume that one area of the skeleton necessarily represents the state of the whole, although Bayley ('43) indicated a good correlation between maturation of the hand and knee over the age of 13 years. But this method is expensive and takes no account of shape changes, and is difficult to use for large samples of children; it has the added disadvantage that radiation is increased. In longitudinal studies this is an important consideration.

The inspectional technique is currently most often used. After discussions with Hellman ('28) and Flory ('36), Todd ('37) described in great detail the image changes in the growing areas of the long and short bones in many areas of the body, but the only published work concerned the hand and wrist. This, then, was the first detailed "atlas" though in fact, one was published as long ago as 1902 by Wilms. One compares radiographs of the hand and wrist with standard films, described in detail, typical of different ages. Greulich and Pyle ('50) revised Todd's work and added details on the round bones in the wrist and it is this atlas which is used so widely at present. There is an atlas giving standards for Dutch children (Speijer, '50); a report by Mackay ('52) re-

lating to standards for East African children; and a recent atlas on the knee (Pyle and Hoerr, '55).

The wrist and hand have been used so frequently because there is such a variety and number of bones available, and the procedure is simple and cheap. At certain ages little activity may appear in certain areas and this has led to the study of other situations (e.g., the knee) for comparative purposes.

A refinement of the inspectional method is the Red Graph Method (Pyle et al., '48). This gives a range, and probably a better impression of the state of affairs in an individual. But it also leads to a discussion on the short-comings of the inspectional technique. It is this possible wide variation in the state of maturity of individual bones that points to a drawback: The Inspectional Method does presume a fixed *pattern* of development of the bones and although many individuals fit into the pattern, many do not. Not infrequently one particular bone is found which is greatly advanced or retarded compared to the standard, yet all the others fit closely. How is one to "age" this individual's skeletal maturity? It appears that such patterning is genetically determined, (Buschke, '34; Reynolds, '43; Sontag and Reynolds, '44; Garn, '56). Further disadvantages are:

(a) That the measurement obtained is necessarily not a fixed measure;

(b) That since girls mature skeletally faster than boys, (first noted by Pryor, '25) two sets of standard films are necessary, for any female "bone age" will not be the same as the corresponding male "age;"

(c) That a subjective observer error in inspecting the films can be large. (Mainland, '53, '54, measured this error but enlisted a very inexperienced observer in the test. The usual error of experienced assessors does not invalidate the method.)

(d) That the standards so used are those of a sample of children of one racial and geographical background. The African, as an example, appears to have a different pattern of early skeletal maturation, (Mackay, '52; Deane, '56; Falk-

ner et al., '58). Clearly the racial, and again the genetic, factor is important.

It must be strongly emphasized that for clinical use, atlases and methods related to their use have a place of great value, but in unraveling the problems presented, as a research tool they may lack somewhat a degree of exactness.³

Acheson ('54) drew attention to some of these points and presented a method (The Oxford Method) in which using the hand and wrist, and the knee, simple points were given to individual centers as they appeared and further points added when definite shape changes occurred. He studied the first 5 years of life and based his method on examination of a series of *longitudinally* studied children. By seeing in such an individual's films definite shape changes which were identifiable in all films, he used these maturity indicators (described by Todd, originally) as milestones and places for the awarding of point. [In order to offset the great contribution of total points made by the rapidly appearing epiphyses of the long bones of the hand he, in fact, originally "weighted" the scoring by giving fewer points to these centers in order to achieve equilibrium between all the bones in this area. Robinow ('42) suggested round bone and long bone epiphyses may be controlled independently. These were called "corrected points."] This method gave a measure other than time to skeletal maturity and obviated many of the disadvantages of previous techniques.

We are still left with the questions: Is this method a fine enough measure? Does it truly, within critical limits, enable us to unravel the questions posed in the introduction?

First, there is the question of subjective observer error. Clearly in deciding whether such and such a shape (maturity indicator) has been achieved brings in subjectivity. An added technical point of great importance is the positioning of the area under the x-ray tube. In observing shape, obliqueness of x-rays is of great importance. With this in mind, the following procedure was carried out.

³Since preparation of this paper, a new edition of the Greulich and Pyle Atlas mentioned is presently available. Many of these points are answered.

Skeletal maturity of a further sample. Serial films taken of children from the current longitudinal study of growth and development at the Child Study Center, University of London, were assessed using the Oxford Method. (For the details of the sample, method of recruitment, and investigations carried out, etc., reference may be made to Moore, Hindley and Falkner, '54). Briefly, the sample consists of "healthy" unselected children, and these same children are followed regularly from birth. The children are seen within rigid time limits.

Films were available up to three years of age. The author assessed the films according to the Oxford Method after reading the original article mentioned. The films were then mailed in batches (causing periods of great anxiety, there being no copies) to Dr. Acheson who most kindly independently read the films.

Table 1 shows the very high correlation between the two observers.

TABLE 1

Intra-class correlations between two independent assessments of 806 radiographs of the hand and wrist by two observers using the Oxford Method.

AGES AT WHICH FILMS TAKEN (BOYS AND GIRLS)	NUMBER OF FILMS INVOLVED	R
13 weeks	154	.931
26 weeks	154	.847
39 weeks	127	.903
1 year	115	.984
18 months	119	.959
2 years	85	.936
3 years	52	.971
Total	806 ¹	

¹ Overall correlation on all films; $r = 0.987$.

It is vital to point out two things. First, the remarkable correlation is not all that surprising when one realizes that in the first three years of life the observers were counting, on the whole, the appearance of the number of centers and a much

TABLE 2

Mean Oxford crude points of hand and wrist. Child Study Centre boys and girls at given ages, with the 5th and 95th percentiles, correct to one decimal place¹

	4 WEEKS	13 WEEKS	26 WEEKS	39 WEEKS	1 YEAR	18 MONTHS	2 YEARS	3 YEARS
No.	68	71	73	61	56	55	39	22
Girls, mean	0.5	1.4	2.7	4.6 (3.9)	8.5 (6.2)	17.2 (9.6)	22.0 (12.1)	27.6 (15.1)
5th P	0.07	0.2	1.1	1.7 (0.4)	2.1 (1.8)	8.1 (5.1)	13.5 (8.6)	24.5 (10.6)
95th P	2.2	3.0	4.5	11.2 (7.6)	18.7 (11.2)	25.1 (13.1)	28.0 (15.1)	34.0 (20.2)
No.	70	83	81	66	59	64	46	30
Boys, mean	0.3	1.2	2.5	3.3	4.3	8.7 (6.3)	15.1 (8.8)	23.6 (13.1)
5th P	0.06	0.2	0.6	1.3	1.7	2.8 (3.31)	4.8 (4.2)	11.3 (6.0)
95th P	2.1	2.4	4.8	6.2	8.2	16.7 (9.5)	23.4 (13.3)	29.0 (16.8)

¹ Figures in parentheses are "corrected Oxford points." The term "corrected points" has already been explained earlier in the text. Acheson ('57) now states that it is more desirable not to adjust such awarding of points and he has not done so in his latest point system of the pelvis.

TABLE 3

Gains of mean crude Oxford points in 13-week incremental periods at given ages. Child Study Centre children, boys and girls. Hand and wrist. Corrected Oxford points in parentheses

	13 WEEKS	26 WEEKS	39 WEEKS	1 YEAR	18 MONTHS	2 YEARS	3 YEARS
Boys							
No.	58	70	50	40	43	32	19
Increment	1.2	1.4	1.1	0.9	2.1 (1.0)	3.2 (1.4)	2.4 (1.2)
Girls							
No.	48	56	49	40	37	26	11
Increment	1.5	1.3	2.0 (1.2)	4.6 (2.8)	4.4 (1.8)	3.0 (1.4)	1.2 (0.8)

smaller proportion of shape changes. Clearly, later in life the correlation might be much less. Acheson ('57) reread a large set of films of the pelvis (having devised a point system for this area) after some time, and had an overall correlation

TABLE 4
Comparative mean corrected Oxford points; hand and wrist

	BOYS				GIRLS			
	CSC	Oxford	Dakar	Paris	CSC	Oxford	Dakar	Paris
10 days	—	—	0.4	—	—	—	0.8	—
4 weeks	0.3	—	—	0.1	0.5	—	—	0.4
13 weeks	1.2	—	1.7	1.2	1.4	—	2.0	1.8
26 weeks	2.5	2.6	3.0	2.8	2.7	2.9	2.8	3.5
39 weeks	3.3	—	3.7	3.7	3.9	—	3.4	4.6
1 year	4.3	4.4	4.3	4.6	6.2	5.6	4.6	5.8
18 months	6.3	6.9	5.1	6.2	9.6	9.2	5.3	8.9
2 years	8.8	9.4	—	8.3	12.1	11.7	—	11.3
2½ years	—	11.6	—	10.4	—	13.8	—	12.7
3 years	13.1	13.5	—	—	15.1	15.7	—	—

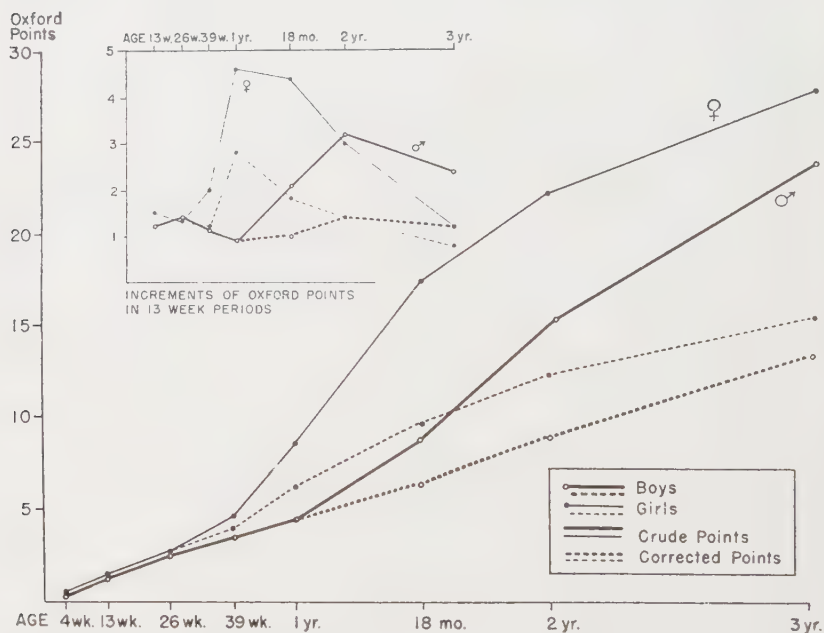


Fig. 1 Mean distance and velocity curves of Oxford points (crude and corrected) of Child Study Centre children.

of 0.9966 with himself. (He, too, found the overall correlation to be higher than the mean and its component parts.) Secondly, the observers had the advantage of being able to view a series of films of the same individuals and this is of great help in deciding on degrees of progression.

Table 2 shows the mean Oxford points of the children in the London sample measured by the Oxford Method with the 5th and 95th percentiles, and these show the wide range of variability in individual children.

The distribution curves of Oxford points at all ages are considerably skewed and thus, standard deviations are undesirable. Table 3 shows the incremental figures over 13-week periods of the London children.

Table 4 compares the means of samples of Oxford, (Acheson, Kemp and Parfitt, '55), Dakar and Paris (Falkner et al., '58), and London children.

Figure 1 shows graphically the results found in tables 2 and 4.

DISCUSSION

The Oxford Method is clearly as accurate as the inspectional techniques, and workable in the situation presented and shows that in the samples investigated:

1. The London children were directly comparable with the Oxford and Paris children;
2. The boys matured more slowly than the girls;
3. The incremental figures show the period of delay in (2);
4. By plotting an individual child's position on the graph, his place regarding the percentiles should give a good indication of his "normality" of skeletal maturity and whether he is a slow, average, or fast maturer. Still better, if two films are available, separated by a time interval, his situation regarding *rate* is found;
5. The London sample of children was not, in company with the other European samples, comparable with the Dakar children. The most interesting features of this comparison are that the Dakar children tend to be more advanced in the early weeks and months after birth but that they lose this advance

and tend to fall behind by 18 months of age. (These studies are longitudinal and thus further information will be available later.) The Dakar children do not show a consistent trend of the female to be advanced over the male in this sample, and in the age period studied but this will presumably appear later (Mackay, '52).

Practically all the Dakar children are breast-fed and it may be that virtually unlimited quantities of breast-milk taken in the tropics leads to increased osteogenesis. In temperate climates it is an impression that this leads to increased formation of fat. An increase in total length *gains* at or near after birth is found too, in the same children compared to the Europeans and this measurement also falls behind at 18 months — another example of the close relationship between growth in height and skeletal maturity. Here perhaps malnutrition is starting to take effect. (Falkner et al., '58).

We are still left with the problem, if height and skeletal maturity are intimately correlated, is there any point in assessing skeletal maturity? Will not an estimation of height tell us just as much in all cases? Clearly in doubtful cases of abnormality of growth to have confirmatory evidence is always useful. Again, in designating the early maturing child from the late maturer the assessment of skeletal maturity may not only confirm, but be a more indicative measure than height. It is now apparent that the state of skeletal maturity may be linked to a useful degree with constitutional or morphological types. (Acheson and Dupertuis, '37.) So of course is height, but by no means on its own. Great research is needed in the complex field of constitutional medicine (Tanner, '56; Falkner, '57) for the rewards may be great, and possibly the most important use of the assessment of skeletal maturity may be in this field as an added tool.

The future

If "100% level of morphological maturity is inevitable in the healthy human" (Krogman, '50) then perhaps we could best assess skeletal maturity as a percentage achieved at any

age and be provided with a range of "normality." This would mean having available serial films of large numbers of children from stated different environmental and genetic backgrounds. Ideally the site chosen should be checked with other areas in the body. This is a large undertaking. Tanner ('58) and his colleagues are engaged on such a process at present for use with certain internationally co-operating growth studies.

Those engaged in multi-disciplinary longitudinal projects may next be able to test the validity of such methods and the place of skeletal maturity in research. It may be that the answer does not lie with the radiologists but perhaps within other disciplines. Acheson ('54) clearly pointed the way out of the unsatisfactory situation and stimulated the realization that much needs to be done in this field.

SUMMARY

The concept of skeletal maturity as a separate entity from growth in length of the skeleton is discussed.

Difficulties and methods of its assessment are pointed out.

The Oxford Method of awarding Oxford points for maturational indicators appearing in x-ray films of the hand and wrist is applied to a sample of London children longitudinally followed. Means, the 5th and 95th percentiles, with gains in 13 week incremental periods are given at the ages of 4, 13, 26, 39 weeks, one year, 18 months, two years, and three years.

Independent observations of a series of films by two observers show a very high correlation, and that the method is as accurate as the inspectional techniques. Comparative assessment of skeletal maturity are given for samples of Oxford, London, Paris, and Dakar children. The European samples tend to be dissimilar in patterns of skeletal maturity compared to the Dakar children. Possible reasons are put forward.

The future of the assessment of skeletal maturity and its usefulness is discussed.

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CRANIAL CRESTING PATTERNS AND THEIR SIGNIFICANCE IN THE HOMINOIDEA

J. T. ROBINSON

Transvaal Museum, Pretoria

TWELVE FIGURES

INTRODUCTION

Mammalian cranial crests have seldom been regarded as important structures and their nature has come to be understood largely through study of the principles of skull growth. In recent years attention has been concentrated on primate cranial crests as a result of the discovery of some australopithecine remains having these structures. Well-developed sagittal crests occurred in a few skulls but the nature of creasting in the occipital area was not at first clear. From various lines of reasoning Broom and I regarded the sagittal crest as being confined to the middle part of the vault and not associated with a large nuchal crest. This conclusion was challenged by Zuckerman ('54) and Ashton and Zuckerman ('56). These authors produced much evidence to show that, with quite negligible exceptions, mammalian skulls having a sagittal crest invariably also have a nuchal crest. They further claimed that what is known of australopithecine creasting fits perfectly into the pattern seen in pongids. These authors did not attempt to give any explanation of the difference in hominid and non-hominid creasting. The present discussion seeks to put on record the known evidence regarding australopithecine creasting; to discuss the factors which modify the creasting process and suggest a simple explanation of creasting to account for all the known higher primate creasting patterns as well as for the evolution of the hominid from the non-hominid type.

Terminology

The terminology here employed differs slightly from that previously employed by me. In order to make it comply with Article 4 of the International Rules, the term *Euhomininae* is replaced by *Homininae* as a subfamily name to include that part of the family *Hominidae*, other than the *Australopithecines*, which comprises forms that are not only erect-walking but also exhibit indications of cultural activity of a sort characteristic of true man. The vernacular term is thus "hominine" for this group. The term "prehominids" used by me heretofore is replaced by "prehominines" in the interests of logic and consistency. It is entirely interchangeable with the term "australopithecine."

The gorilla, chimpanzee, orang, siamang, gibbon and related fossil forms together comprise the pongids (family *Pongidae*); the pongids and hominids together constitute the hominoids (superfamily *Hominoidea*).

Nature and development of crests

It is important to appreciate at the outset that all cranial crests or ridges are not identical in origin.

(a) *Torus*. A torus is a bony thickening which is a part of the skull architecture and is usually rounded, not sharply crested. Tori are regarded by Weidenreich ('40) as strengthening structures. Whatever their true nature may be, they are not necessarily concerned with musculature except indirectly.

Crests, on the other hand, are directly related to muscles and two forms may be distinguished.

(b) *Simple crest*. Where a muscle attachment is free and not closely bordered by another muscle, a roughened zone or line commonly marks its limit. Such a peripheral line may sometimes develop into a crest and may even be very pronounced. A crest of this sort may be termed a simple crest and results from the action of a single muscle or muscle group. (See fig. 1).

(c) *Compound crest.* When two muscle masses approach each other closely enough to meet, actual contact is avoided by a bony upgrowth of the outer table of the skull. Each muscle involved in effect produces a simple crest, but as they are



Fig. 1 Simple crests caused by the temporalis muscles in a male orang-utan.

applied to each other, not two but only one crest results. This is a compound crest and has muscle attached on both sides. (See figs. 3, 6, 8, 9, and 10.)

The development of a compound crest seems to be a response to the need for additional area of attachment for muscles in a situation where space is restricted. The upgrowth of the bone provides the requisite additional surface. It has been

shown experimentally that these local factors, rather than intrinsic genetic factors, determine the presence and extent of the crest, (Washburn, '47). The nature and disposition of the cranial musculature are therefore of prime importance in determining compound crest formation in the skull.

Simple crests are clearly also determined by extrinsic factors; but space shortage is not a critical factor, as it is in compound crest formation. The angle at which the muscle fibers arise from the bone surface may be a factor in the formation of simple crests.

In the present study we are concerned with crests, not tori; specifically, the sagittal and nuchal crests. As is well known, the former develops as a result of the close approximation of the two temporalis muscles while the nuchal crest results from a similar occurrence involving the temporalis muscles on one hand the nuchal musculature on the other.

Cresting in the pongids

Ashton and Zuckerman ('56) have gathered together useful data on crests and their development in the pongids as well as in a number of other primates. From this study it appears that the following firm conclusions can be drawn about cresting in the pongids:

(a) At least a partial compound nuchal crest, formed by the temporalis and nuchal muscles, is invariably present in mature adults.

(b) Ontogenetically, the nuchal crest always appears before the sagittal.

(c) A sagittal crest never develops in a skull which lacks a definable nuchal crest.

(d) The nuchal crest becomes more prominent as the sagittal crest develops.

(e) The nuchal crest starts to form before eruption of the permanent dentition has been completed.

These conclusions appear also to hold for the other non-hominid primates studied, which include some Old World monkeys as well as one from the New World.

Cresting in hominines

Ashton and Zuckerman ('56) point out that in modern man the temporal and nuchal musculature is relatively smaller and the cranium relatively larger than in any of the other primates studied in the present connection. Consequently, neither sagittal nor nuchal crests are ever formed, in spite of general similarity in the disposition of the muscles. No fossil hominines are known which have either of these crests. Weidenreich ('40) writes of sagittal crests in *Pithecanthropus*, but in fact is referring to thickenings of the skull in the region of the midline which are not due to action of the temporalis muscles.

The situation is actually a little less simple than the above indicates. It appears to be true that no hominines are known which have sagittal crests. It also appears to be true that none is known in which even a partial compound nuchal crest formed by the temporalis and nuchal musculature occurs. But crests *do* occur along the superior nuchal line in this group. These may be either simple or compound. The commonest form of compound crest is very small and occurs in about the middle third of the superior nuchal line between inion and mastoid. This is due to the joint action of nuchal muscles with the occipitalis belly of the epicranial aponeurosis. Simple crests of considerable size may occur, but these are usually formed nearer the sagittal plane — as in a Bantu skull in the collection of this department (fig. 2). It is therefore necessary to distinguish between compound nuchal crests formed by the temporalis and the nuchal muscles and others not involving the temporalis. In this paper compound nuchal crests of the former sort are referred to as “compound (T/N) nuchal crests.”

Cresting in the prehomines

The available information in respect of cresting in this group involves the two quite distinct forms *Paranthropus* and *Australopithecus*.

A large body of evidence bearing on the differences between these two genera is now available and some of it has been set forth in Robinson ('54 a and b, '56).

(a) *Paranthropus*

The large sample of *Paranthropus* now known contains only three adult skulls preserved in such a manner that the presence or absence of a sagittal crest can be determined. All three of these actually have such crests. This suggests

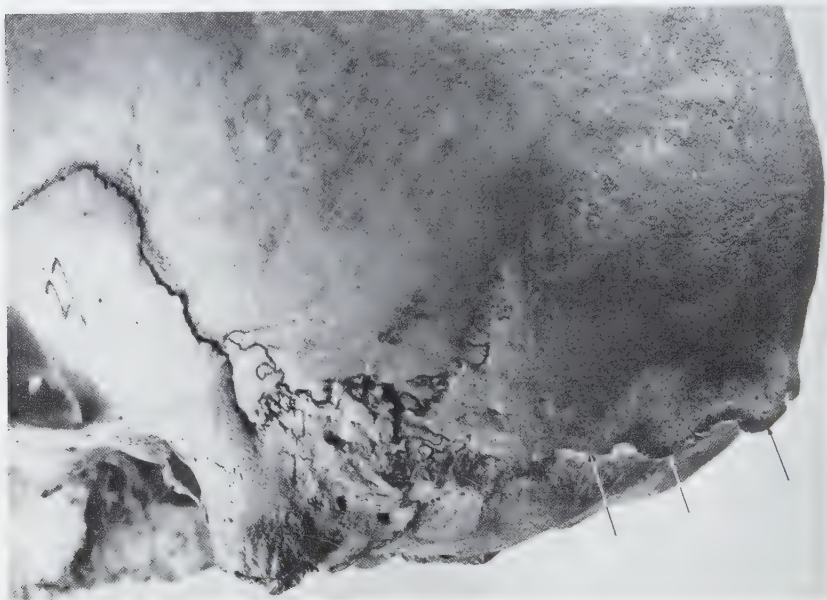


Fig. 2 Nuchal cresting in a Bantu skull. The temporalis muscles did not approach this crest at all closely.

the possibility that this crest was usually present in adults. The effective sample number is far too small to prove this but two points increase the probability that such a conclusion is correct. Firstly, one of the skulls (SK 48) appears to have been that of a female. This has *in situ* the right upper canine, the breadth dimension of which falls into the modal class of the smaller-size half of a bimodal histogram obtained from the Swartkrans sample of this tooth (Robinson, '56,

pp. 152-154). For a female to have a moderately developed sagittal crest suggests that the latter was probably common in adults, implying as it does that most males probably possessed it also. Secondly, the sample of 273 permanent and 38 deciduous teeth from the site provides evidence of only a small degree of sexual dimorphism. This suggests the possibility that crestring may not have differed greatly in the two sexes. It is therefore probable that the majority of adult *Paranthropus* individuals possessed sagittal crests.

The most informative of the above specimens is SK 49; hence it will be considered first.

SK 49. This specimen consists of the greater part of a crushed and sheared skull. The preservation of the bone is good so that where the outer surface of the skull is still present the finest detail is apparent. All of the maxillary premolars and molars are *in situ*, although P³ is damaged bilaterally.

The greater part of the supraorbital torus is missing but a part of the right extremity is still present where it passes down into the postorbital constriction. The right inferior temporal line, which is quite evident but not strongly developed, passes from this area as a curved line which reaches the sagittal plane at a point which must be anterior to bregma. This point is approximately three-and-a-half centimeters behind the main transverse plane of the supraorbital torus and from it a low sagittal crest passes back for a distance of 26 mm. At the broken end the crest is 2.1 mm high and has a groove in the midline. Judging from other skulls of this genus the break must coincide approximately with the position of bregma. No sutures are apparent, either sagittal or coronal. (See fig. 3.)

Part of the occiput is well preserved, as is a considerable portion of the left parietal, which is, however, partly distorted. The inion is present as a small, downward projecting, triangular process. On either side the superior nuchal line is preserved as a poorly developed ridge — less a ridge, strictly speaking, than simply a change in direction of the surface of

the bone. On the right side the bone is preserved for a centimeter only along the superior nuchal line, but on the left side it is preserved for the full distance across onto the mastoid. The superior nuchal line is weakly developed for a distance of 19 mm to the left of the inion, is then drawn out into a low ridge for a distance of 27 mm, after which it is again a barely perceptible line for the remaining 24 mm of the specimen. The presence of the external auditory aperture and the fact

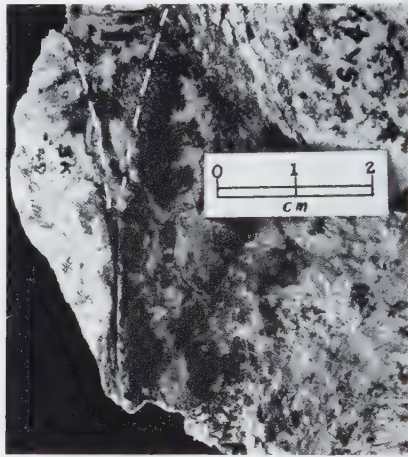


Fig. 3 Portion of the frontal region of SK 49 showing the anterior part of the sagittal crest. The course of the temporal lines, visible on the specimen, are indicated by broken lines. The preserved part of the crest has suffered slight damage both anteriorly and posteriorly.

that at the point of breakage the bone is highly cellular, identify the latter point as on the mastoid. The ridge or small crest that forms approximately the middle third of the superior nuchal line reaches a maximum height of 3 mm in the middle but rapidly diminishes in height on either side. The length of the planum occipitale is 28 mm in the midline; that is, lambda is separated from the inion by that distance. The maximum width of the planum occipitale will have been approximately 86 mm. The latter is arrived at by measuring the direct distance between the inion and the point at which

the lambdoid suture intersects the superior nuchal line on the left side and then doubling this figure. This procedure will not give the exact original measurement but will be close enough for present purposes. This specimen thus had a planum occipitale of substantial size.

The lambdoid suture is still quite open and is, along with the sagittal suture, pulled slightly open in the region of lambda. This shows that fusion had not yet commenced in this region, even endocranially. Although the bone just anterior to lambda has been disturbed, the sagittal suture can be seen quite easily under a low-power stereoscopic microscope, when the smoothed edges of the suture are readily distinguished from the edges of small cracks. The suture can be followed for about a centimeter anterior to lambda and it is clear that at least one small sutural bone is present. No trace whatever of a sagittal crest occurs on either the planum occipitale or the area of disturbed bone anterior to it.

The left inferior temporal line can be followed without difficulty from above the external auditory aperture, whence it passes in a curve over the parietal (fig. 4). The minimum distance between the inferior temporal line and the small crest on the superior nuchal line is 10 mm. The medial end of the crest is separated from the inferior temporal line by 18 mm. The temporal line therefore not only fails to reach the crest, but also is not parallel to it in the appropriate region. The point of closest approach of the temporal line to the superior nuchal line is not in the area of the small crest but between the mastoid and the lambdoid suture, where the separation is 9 mm. It is therefore manifest that the formation of the small nuchal crest in this specimen is in no way related to the temporalis muscle.

At a distance, in the midline, of one centimeter anterior to lambda the separation between the inferior temporal line and the sagittal suture is just under two centimeters. Owing to a small amount of disturbance of the bone this distance cannot be measured with complete accuracy.

It is important to obtain a reliable estimate of the age of this specimen. Because the lambdoid suture is still open, Ashton and Zuckerman ('56, p. 605) state categorically that it was "at most a young adult." This statement is based on the assumption that suture closure in the australopithecines

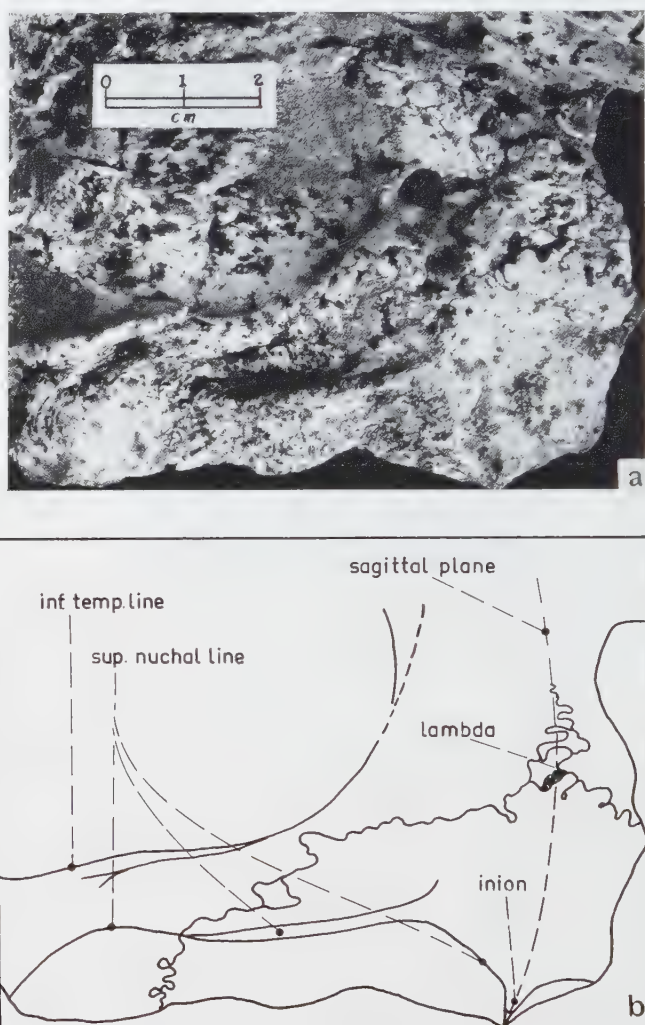


Fig. 4 (a) Photograph of part of the occipito-parietal area of SK 49. (b) Tracing of (a) with main features indicated.

will occur at the same relative age as in the pongids. Observation, on the other hand, shows that this specimen not only had the full permanent dentition in functional position, but that M^2 has all the cusps well worn and that M^3 has both anterior cusps and the anterior margin of the anterior fovea appreciably worn and small wear facets present on the posterior cusps (fig. 5). Since there is close correlation between the degree of wear exhibited by upper and lower teeth of the same individual, as Ashton and Zuckerman ('50, p. 474) have noted, it is clear that this specimen satisfies the dental

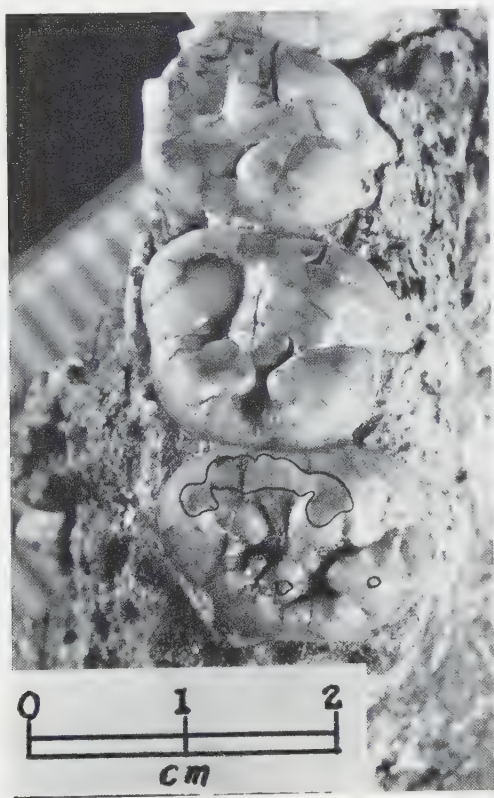


Fig. 5 The molars from the right side of the palate of SK 49. M^1 is considerably worn over the entire occlusal surface with dentin already exposed. M^2 is well worn over all the cusps, but dentin had not yet been exposed. M^3 has flat wear facets in the areas outlined in ink.

criteria used by these authors for their category "old adult." It must therefore be regarded as a fully mature adult.

SK 48. This specimen is the most complete *Paranthropus* skull known at present. The full permanent dentition was in position when the animal died but some teeth have subsequently been lost. The left molars are all *in situ* and well preserved, with M^2 worn on all cusps and M^3 worn over most of the occlusal surface. This specimen is thus also fully mature.

Most of the left and some of the right parietal are missing, as is most of the planum occipitale. The greater part of the planum nuchale is present but crushed out of position. Both inferior temporal lines can be followed anteriorly to the point where they fuse into a sagittal crest. This point is 29 mm posterior to the equivalent point from which measurement was made in SK 49, and 51 mm distad of glabella — which bulges forward appreciably from the general line of the supraorbital torus. The crest is preserved for only 16 mm and at the break is 3 mm high. This crest was apparently slightly larger than that in SK 49.

A small crest with a maximum height of 6 mm occurs in the middle third of the right superior nuchal line. A small area of the planum occipitale is intact from about the middle of the crest to a point half a centimeter medialward of the medial extremity of the crest. On this there is no trace whatever of a temporal line leaving the small crest, nor is there any indication of a nuchal crest in the midline. The crest thus appears to have exactly the same nature as that in SK 49.

SK 46. In this specimen the greater part of the left half of the neurocranium is present, slightly distorted, but almost the whole of the right side and the occiput are missing. The midline is preserved from immediately posterior to glabella for a distance of 105 mm. This skull belonged to an aged adult; M^3 already has dentin exposed and M^1 has no occlusal enamel remaining.

A sagittal crest arises 25 mm distad of the reference point used in the previous specimens. *Paranthropus* has a well

defined hollow between glabella and bregma and the above point coincides with the bottom of this depression. The crest is preserved for a distance of 70 mm and at the break is 9.1 mm high with the top of the crest intact. A centimeter anterior to the break the height is 12.6 mm — anterior to this point the top of the crest is damaged for some distance (fig. 6).

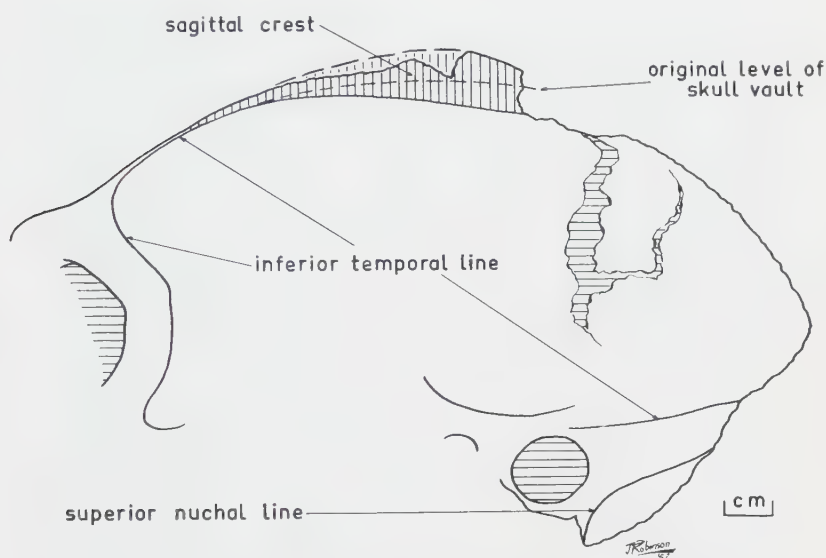


Fig. 6 Part of the neurocranium of SK 46 showing the preserved portion of a well developed sagittal crest. Part of the crest margin is damaged and is here restored; the crest margin posteriorly is quite undamaged and indicates rapid diminution in height of the crest distalward. The skull vault has been depressed slightly in part of the crest area; the probable original contour is indicated. This depression has not affected the crest as such except for bending it very slightly to the left in a manner not affecting height measurements.

These figures suggest that the maximum height of the crest occurred roughly two-and-a-half centimeters posterior to bregma; the crest decreasing in height both anterior and posterior of this point.

The supramastoid crest clearly marks the lower limit of the temporalis above the mastoid (fig. 7). This crest is not directly continuous with the root of the zygoma but is a little

lower down. The line reached by the nuchal musculature on the mastoid is also clearly visible. Just posterior to the external auditory aperture these two lines are separated by a distance of 15.1 mm, the separation decreasing to 7.6 mm at a distance of 24.9 mm behind the posterior margin of the external auditory opening. At this point the specimen is

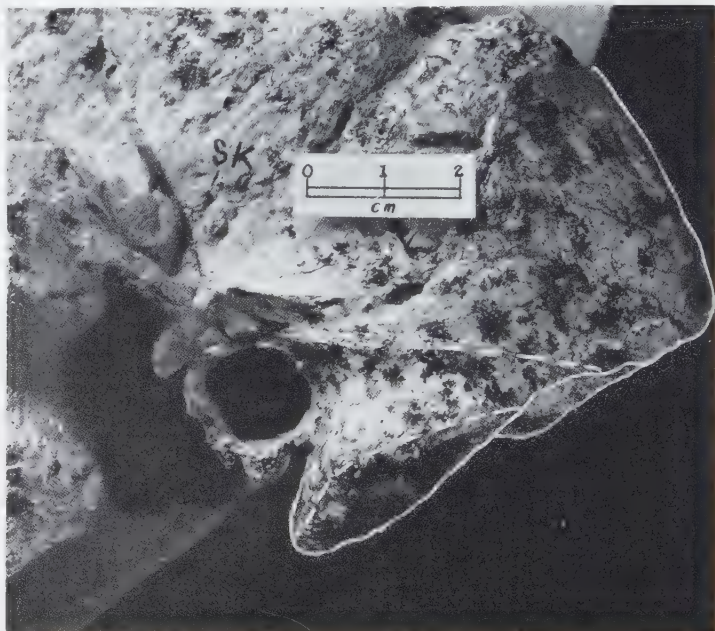


Fig. 7 The auditory region of SK 46 showing the well separated inferior temporal line (supramastoid crest) and superior nuchal line.

broken; it coincides almost exactly with the point at which the inferior temporal and superior nuchal lines approach each other most closely in SK 49. In the latter the separation is 9 mm. There is thus a wide, shallow groove separating the temporalis and nuchal muscles for a distance of at least two-and-a-half centimeters behind the ear in a specimen with a strongly developed sagittal crest.

Discussion. The sample from Swartkrans provides only three adult specimens relevant to the present inquiry. All

three had the full permanent dentition in functional position with the second molar worn over the whole occlusal surface and wear evident on the third molar; all three were thus mature adults. Evidence from SK 49 shows that lambdoid suture closure would have occurred well after maturity since it is still open in a fully mature individual.

All three specimens have sagittal crests arising well forward of the vertex and anterior to bregma also. No adults lacking a sagittal crest are known. SK 49, although having a crest anteriorly, shows no trace of it over a distance of nearly 4 centimeters anterior to theinion. Judging from the course of the inferior temporal line on the left parietal, the crest must have terminated anterior to a point midway between bregma and lambda. SK 46 has a well-developed crest reaching a maximum height of no less than 12.6 mm about two-and-a-half centimeters posterior to the estimated position of bregma. The crest is preserved for only a centimeter further and in this distance its height decreases rapidly, suggesting that it was either small or non-existent further back. SK 48 has a crest anteriorly but no nuchal crest is present in the sagittal plane—which would have been the case had the sagittal crest extended back to the superior nuchal line.

The condition described here does not occur in any of the three great apes and the nearest approach to it in the pongids as a whole is in a single gibbon skull mentioned by Ashton and Zuckerman ('56). This has a minute sagittal "crest," anteriorly situated, which is a centimeter-and-a-half long and half a millimeter high. This specimen has a compound (T/N) nuchal crest.

The occiput of SK 49 shows conclusively that the inferior temporal does not reach the superior nuchal line, the point of nearest approach leaving a gap of 9 mm. Ashton and Zuckerman ('56, p. 605) are therefore not correct in writing that, "The significant point is that a nuchal crest, of the kind defined in accounts of the actual fossils, and as can be seen on casts, would not have been present in *Paranthropus* if the

posterior fibers of the animal's temporalis muscle had not already reached the superior nuchal line." Although the inferior temporal line is clearly defined and excludes the possibility that the temporalis reached the superior nuchal line, there nevertheless is indication of muscle attachment on the upper side of the small crest. The only muscle that could be involved is the occipitalis.

SK 48 has no indication of the inferior temporal line on the planum occipitale just above the small, incomplete nuchal crest. The latter would thus appear to be of the same sort as that in SK 49 and therefore not a compound (T/N) nuchal crest. In SK 46, at a point on the superior nuchal line roughly equivalent to that at which the relevant temporal and nuchal lines approach each other most closely in SK 49, their degree of separation is only slightly less than in the latter specimen despite the powerfully developed sagittal crest of the former. This condition, in conjunction with the fact that the sagittal crest decreases rapidly in height in the latter portion of the part preserved, makes it extremely unlikely that the inferior temporal and superior nuchal lines met in this specimen. In pongids with a sagittal crest as well-developed as that in SK 46 these lines meet a short distance behind the ear — and commonly form a pronounced nuchal crest. (See figs. 8, 9 and 10.)

The chief features of crest-formation in SK 49 are well defined and readily determined and what evidence is available from the other two specimens fits into the same pattern, suggesting that we are here dealing with the normal *Paranthropus* pattern. This manifestly differs radically from that of the pongids as defined by Ashton and Zuckerman ('56), being in disagreement with all 5 major features of pongid cresting determined by these authors and listed earlier in the present paper.

(b) *Australopithecus*

The sample of this genus from Sterkfontein and Makapan Limeworks provides 6 specimens which give some indication

of the nature of cranial crest-formation. Of these, 5 had no sagittal crest. The sixth, from Makapan, does not have a sagittal crest on that part of the neurocranium now available, although it is my opinion that a small crest was present anteriorly.

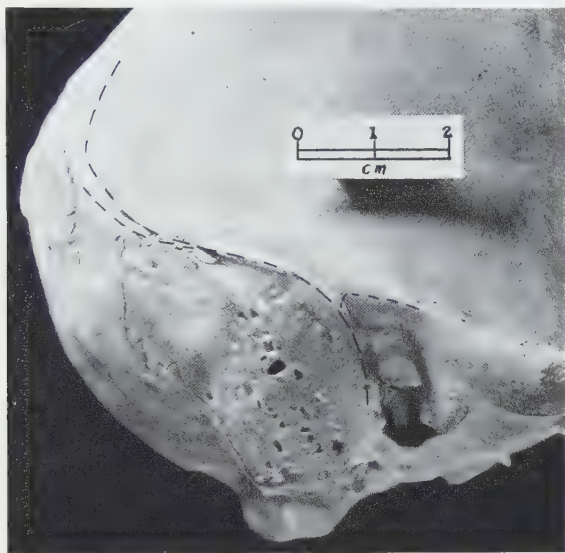


Fig. 8 The auditory region in a female chimpanzee. Although the compound (T/N) nuchal crest is very small it nevertheless arises close behind the ear opening.

The latter specimen was first described by Dart ('48) and consists of the posterior parts of the parietals and the greater part of the occiput. For details the reader is referred to the original description. Teeth are lacking, hence this means of ageing the specimen is not available. However, both the lambdoid and sagittal sutures are already closing. If suture closure occurs at a roughly comparable time in this genus to that in *Paranthropus*, then this specimen is older than SK 49 and hence also fully mature. This is the only guide, at present available, to the age of this individual and, while one would prefer not to have to make this assumption.

it is more legitimate than applying either pongid or hominine suture-closure criteria.

The superior nuchal lines are clearly defined and meet at a small but distinctinion. On either side, near the point where the superior nuchal line reaches the lambdoid suture, the former is slightly prominent in the form of a low, broad

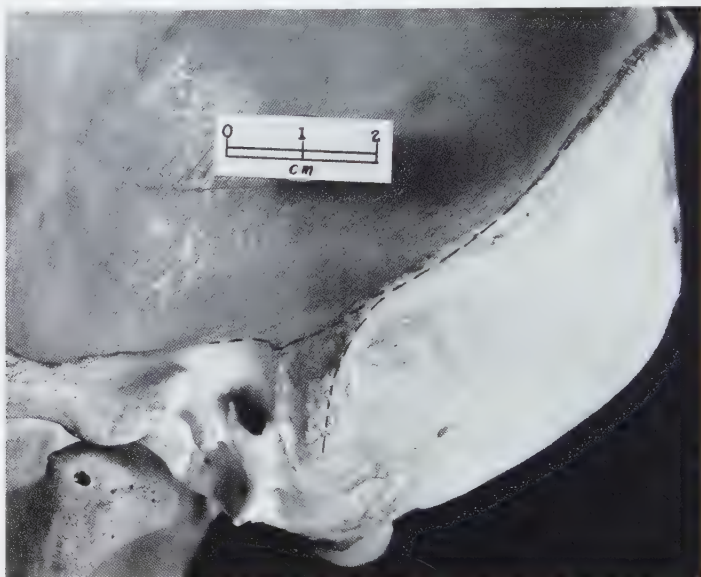


Fig. 9 The auditory region in a female orang-utan with moderate development of the compound (T/N) nuchal crest all along the superior nuchal line. The nuchal crest arises close behind the ear opening. This specimen had a very small, posteriorly situated sagittal crest.

thickening typical of simple crests. The inferior temporal line approaches, within about a millimeter, the superior nuchal line but does not actually touch it. That the muscles of the two lines were not actually in contact is also shown by the simple nature of the small nuchal crest. As in SK 49, the point of nearest approach of the two lines is not opposite the middle of this nuchal thickening. The direction of the temporal line deviates sharply from that of the superior nuchal line in this region.

The inferior temporal line sweeps up in a flat arc from near the superior nuchal line and almost reaches the sagittal suture at the broken edge of the specimen. The break occurs at a point a little more than halfway from lambda to bregma as



Fig. 10 The auditory region in a male orang-utan showing the compound (T/N) nuchal crest arising immediately behind the ear opening. The crest appears to arise some distance behind the ear opening, but this is due to the fact that the crest projects strongly lateralward of the auditory opening. This specimen did not have a sagittal crest (see fig. 1, for frontal view of same specimen).

judged from other *Australopithecus* specimens. The separation between the two inferior temporal lines at the break is half a centimeter. The other parieto-occipital specimen from this site has well defined inferior temporal lines which do not approach each other quite so closely. The specimen is broken approximately a centimeter posterior to bregma and at this point the two lines are still converging. It is therefore reasonable to assume that this is also true of the former specimen

and thus that the two lines would have met by the time the position of the break in the second specimen had been reached. It is therefore quite possible that a small sagittal crest was present in this specimen at about the position of bregma.

Sts. 5 from Sterkfontein is an undistorted and almost complete skull. All vault sutures are almost completely closed, internally and externally; hence the specimen is mature. The preservation of the outer table is, unfortunately, such that

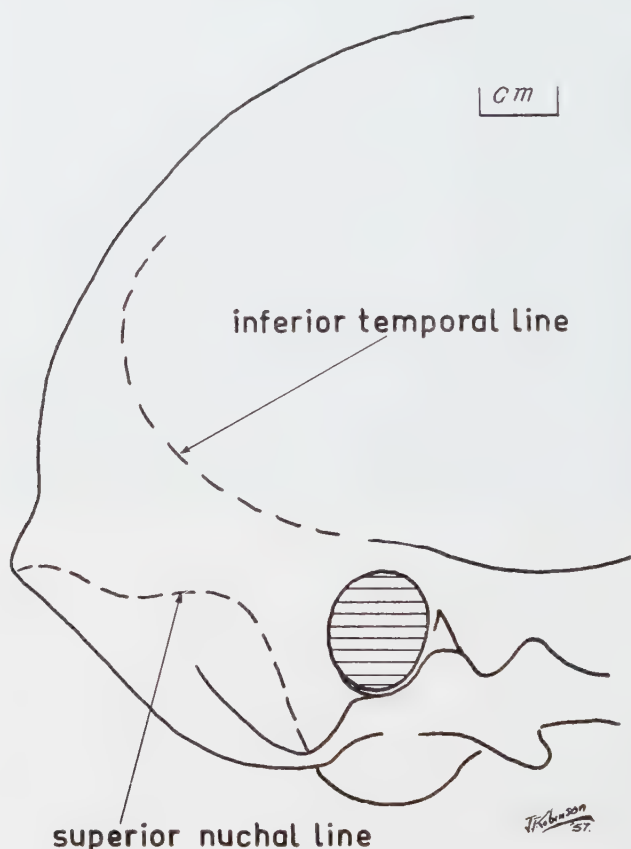


Fig. 11 The auditory region of skull 5 from Sterkfontein showing the inferior temporal and superior nuchal lines which are well separated. The course of the superior nuchal line on the mastoid is not evident on this specimen but this portion has been drawn in from other specimens from the same site.

fine detail can no longer be seen. There is no nuchal crest, but an occipital torus similar to that common in primitive hominines is present. From what can be seen of the inferior temporal lines they do not appear to have approached either the superior nuchal line or the sagittal suture as closely as in the two Makapan specimens mentioned (fig. 11).

Discussion. From the small amount of data available concerning crests in *Australopithecus* it is clear that, as in *Paranthropus*, no compound (T/N) nuchal crests are known. As in *Paranthropus* a relatively well-developed planum occipitale is present in adults (5 specimens). Contrary to the *Paranthropus* condition, sagittal crests do not appear to occur commonly in *Australopithecus*. No instance of such is known, but one specimen from Makapan Limeworks may have had a small, anteriorly-situated crest.

The crestring pattern in *Australopithecus* therefore also differs clearly from that seen in the pongids.

*Comparison of crestring in pongids,
prehominines and hominines*

From the evidence at present available it is obvious that the crestring patterns of pongids, prehominines and hominines differ from one another.

1. Pongids invariably have a compound (T/N) nuchal crest in mature adults while the other groups do not.

2. Pongids and prehominines may have sagittal crests; known hominines do not have this feature.

3. Owing to the absence of a compound (T/N) nuchal crest in prehominines, when a sagittal crest occurs it differs from the pongid equivalent in that it does not extend right back to the inion.

It is clear from the foregoing discussion that many other minor differences exist, but the three listed here suffice to distinguish between the three categories. It should be noted, however, that whereas on this evidence a prehominine can invariably be distinguished from a pongid, prehominines and

hominines cannot thus be differentiated from one another. What appears to be the usual *Australopithecus* condition is indistinguishable from the hominine pattern. That is to say the distinction between the known prehomines and the known pongids is absolute in this respect and can be seen on any two skulls, whereas that between prehomines and homines is statistical and depends on having representative samples of each group.

The primary cresting pattern

The work of Ashton and Zuckerman on several non-hominid primates, along with what is known of other higher primates and prosimians, suggests that the major features of cresting seen in the pongids are in fact general non-hominid primate features. If this is so — and it certainly seems to be — then the difference between hominids and non-hominids requires explanation, since the former must have developed from the latter. It is of some interest to examine the general features of the cresting pattern in order to see how such differences may come about.

The primary requirement of compound crest formation is that the architecture of the skull and the number and arrangement of the muscles attaching to it be such that the temporalis muscles may meet each other and/or the nuchal muscles. From what is known of the comparative morphology of the primate head it seems clear that the architecture of the neurocranium and the number and arrangement of the muscles on it are broadly comparable throughout this group, as Ashton and Zuckerman have also noted. The basic, primary pattern of crest-formation would thus appear to be the same in all primates and significant differences in the end results of the process should therefore be attributed to influences superposed on this pattern rather than to differences in the primary pattern itself.

It is necessary to consider very briefly some of these modifying influences, of which some are well recognized and all of which are readily recognizable.

Modifiers of the cresting pattern

In listing these modifying factors no particular skull is being considered; the discussion is theoretical and consists simply of noting the logical result of this or that modification of the basic elements involved, providing only that such modifications do actually occur in nature.

(a) Muscle volume and skull size

In a given size of skull, greater muscle volume will normally cover a greater area of skull. Variations in muscle volume thus increase or decrease the probability of crest formation. Similarly, if muscle volume remains constant and neurocranium size varies, the same effect is achieved. In respect of these two factors, whether or not the threshold for crest-formation is reached depends on the relationship between neurocranium size and muscle size, providing that variations in the former do not also involve changes of shape.

(b) Neurocranium shape

This factor is of considerable importance and is best considered separately for each crest.

1. *Sagittal crest.* The main component of the shape factor is variation in the ratio of breadth to height of the neurocranium. More exactly, this involves changes in shape, from front to back, of transverse sections through the neurocranium. This factor may operate in two different ways. In two skulls with muscular cover, which are identical except for calvarial width, a crest could more easily develop in the narrower one. Or, again, if the only difference is in the degree of postorbital constriction, the one with the greater constriction would have the crest, if present, extending further forward. Not only the presence or absence of the crest is thus affected, but also its position when present.

2. *Nuchal crest (compound).* The most important component of this factor in this case is the relationship of the planum nuchale to the rest of the neurocranium. If the planum nuchale is arranged at a considerable angle to the Frankfurt

plane, the inion is thus situated relatively high up the skull and the temporalis can reach the superior nuchal line more easily than in a skull in which the reverse is true. (fig. 12). The effect of a downward rotation of the planum nuchale, round a point in the mastoid area, will be greatest in the sagittal plane and least near the mastoid.

A useful measure of this particular aspect of the orientation of the planum nuchale is the "nuchal-area height index" suggested by Le Gros Clark ('50, '55). This expresses the proportional relationship between the respective heights of inion and vertex above the Frankfurt plane.

The shape component considered in relation to the sagittal crest also influences the nuchal crest. That is, the more a vertical cross-section through, for instance, the mastoids departs from a triangular and approaches a pentagonal shape, the larger the temporalis has to be to reach the superior nuchal line.

3. *Sexual dimorphism.* This factor is of small importance as it applies only at a species level. If it is involved it means only that crests occur more commonly and/or are larger in males than in females. It is perhaps of most importance when attempting to arrive at an estimate of crestring incidence in fossils.

4. *Age.* Age of the individual is a final factor that must be taken into account when making comparisons, since different forms do not always agree in regard to the stage at which a crest first makes its appearance. Any conclusion on the absence of a crest must be based on mature adults.

Ageing skeletal material is not easy. Time of suture closure is commonly used but has serious disadvantages due not only to individual variation but also to very considerable variation from one group to another. Ageing by this means can only be employed in respect of a group which has been studied sufficiently for closure sequences to be known—or at least for some direct evidence to be available from the group itself. This disadvantage shows clearly in the case of SK 49 and the conclusion by Ashton and Zuckerman that it is not a mature

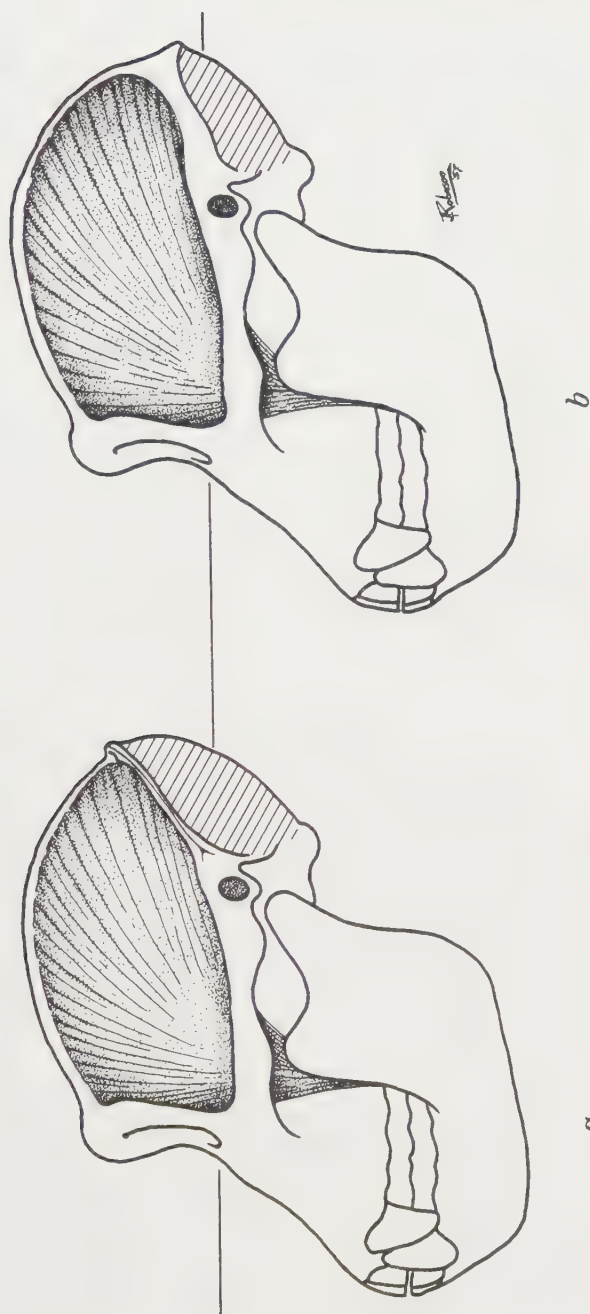


Fig. 12 Diagrammatic illustration of the effect on the nuchal crest of changed orientation of the planum nuchale; (a) is a drawing of the skull of a male chimpanzee with the temporalis muscle indicated, as well as the area of attachment of the nuchal musculature; (b) is a tracing of the same skull but with the planum nuchale rotated downward to a small extent. Muscle size remains the same except that the muscle fibers which originated on the nuchale crest now extend a little further aborally. The changed orientation of the planum nuchale has resulted in the absence of a compound (T/N) nuchal crest.

adult since the sagittal and lambdoid sutures had not yet closed. This conclusion is justifiable only if suture closure in the prehominines follows the time pattern of the pongids. But in this instance the assumption is unjustifiable since there is no evidence in support of it and some is available which opposes it.

Immature specimens can usefully be aged by reference to the stage reached in the eruption sequence of the dentition. Ashton and Zuckerman ('50) have employed a refinement of the dental method to age young and mature adults. Their criterion, which seems entirely reasonable and applicable to higher primates generally, is as follows: specimens having the full permanent dentition and showing wear on the buccal cusps of M_2 , but not on the lingual ones, are young adults; while those showing wear also on the lingual cusps (i.e., on all 5 cusps) are regarded as old adults. Employment of this criterion in the case of Sk 49 leads to a contradiction of the conclusion reached by these authors on the basis of suture closure.

Posture and crest-formation

The final result of the process of crest-formation depends upon the action of the common primary pattern overlaid by that of the modifier pattern. The latter obviously is not the same in all primates. Hominoid cresting types may be placed in two categories; those with compound (T/N) nuchal crests and those without. The pongids fall into the former class, whereas the prehominines and hominines fall into the latter. As far as available evidence goes all other primates fall into the same class as the pongids.

It was pointed out earlier in this discussion that the feature of the modifier pattern which most affects the nuchal crest is the orientation of the planum nuchale and that Le Gros Clark's "nuchal-area height index" provides an indirect measure of this. Ashton and Zuckerman ('51) provide additional data regarding this index which show that the value of the index is low in *Australopithecus* skull 5 and in three

different samples of modern man (the prehominine value falling near the mean values for modern man), whereas the values for each of the extant pongids, chacma baboon, Gray's monkey, black guereza, spider monkey and woolly monkey all appreciably exceed the hominid ones. The minimum value for any of the non-hominids tested exceeds the *Australopithecus* value and overlaps the maximum values of the hominines. The values furthest removed from those of the hominids include, interestingly enough, those of the three larger pongids and the chacma baboon. Measurements of skulls available to me and of photographs in the literature of skulls of all the primate groups suggest that the mean value of this index in all forms falling in the "nuchal crest" group is higher than that of forms in the "no nuchal crest" group. Sts. 5 (*Australopithecus*) is the only adult australopithecine skull now known in which the relevant values for this index can be measured directly. Other skulls available indicate that the orientation of the planum nuchale in Sts. 5 reflects the usual condition in this genus. As far as can be determined the planum nuchale of *Paranthropus* was arranged, if anything, at an even smaller angle than in *Australopithecus*.

It would seem, then, that the presence or absence of a compound (T/N) nuchal crest conveniently separates primates with a planum nuchale arranged at an angle to the horizontal from those in which it is approximately horizontal. This is interesting because an important character, erect posture, yields an identical division. Reflection suggests that this is, after all, not surprising since the horizontal orientation of the hominid planum nuchale is probably a consequence of the erect posture in that group. In this connection Sts. 14, from Sterkfontein, is of great importance. This is a specimen consisting of much of the spinal column and pelvis of an apparently female individual and provides abundant evidence of erect posture. This is supported by some other specimens all of which will be dealt with in detail elsewhere. It seems a reasonable hypothesis, therefore, that the absence of a compound (T/N) nuchal crest in the hominids is related to the

erect posture of this group through the effect of the latter on the orientation of the planum nuchale. It should be noted that the orientation of the latter is not necessarily closely related to the position of the occipital condyles, as is demonstrated by the condition seen in the short-faced squirrel monkey which has the condyles well forward but the nuchal plane arranged in the non-hominid fashion, (see Schultz, '42).

Evolution of hominid crestring patterns

From the analysis of the primary and modifier crestring patterns it is clear that the apparently inflexible rule that a sagittal crest never develops in the absence of a compound nuchal crest is quite spurious. The only extant primates in which sagittal crests occur are all non-hominids which, according to the hypothesis suggested here, have compound (T/N) nuchal crests primarily because of their non-erect posture. But this factor does not affect the presence or absence of the sagittal crest.

Consider the case of a pongid of moderate size, such as the chimpanzee, and assume that it acquired erect posture without significant change in brain or tooth size. The planum nuchale would change in orientation and so reduce the possibility of a compound (T/N) nuchal crest forming. Adaptation to the altered posture would result eventually in a point being reached where all individuals of the population had the planum nuchale sufficiently changed in orientation for the nuchal crestring potential to fall below threshold value. No compound (T/N) nuchal crest would occur but owing to the relatively small neurocranium size and large teeth, the more robustly muscled individuals would still have sagittal crest which would not, however, extend back to the inion. If, at a subsequent stage, the teeth and jaws were reduced and the brain increased in size a stage would be reached where the sagittal crest would also disappear from the population.

Hence, in order to obtain a crest-free form from a more or less generalized pongid or other non-hominid primate, it

would be necessary for the facial skeleton and dentition to be reduced in relative size and for erect posture to be achieved. All of these features are found in modern man. Whether or not he passed through a stage during which sagittal crests occurred in the absence of compound (T/N) nuchal crests depends entirely on whether the enlargement of the brain and reduction of the facial skeleton preceded, succeeded or occurred simultaneously with the achievement of erect posture. All of these are theoretically possible and a decision can only be reached by finding the necessary fossils. The prehomines supply very pertinent evidence. Abundant evidence is now available to show that this group is appreciably more closely related to hominines than to pongids and supply the only available direct evidence of a hominid stage slightly more primitive than the hominine condition. Erect posture is suggested by the orientation of the planum nuchale as previously discussed and very strongly indicated by the postcranial skeleton, but the endocranial volume is still largely within pongid limits and the teeth and jaws are robust. It is therefore not surprising that compound (T/N) nuchal crests are not known in the available material but that well-developed sagittal crests do occur in *Paranthropus* and that small ones may occur in *Australopithecus*. The reason for this difference in incidence and size of this crest in the prehomines is obvious. *Paranthropus* has not only a relatively low calvarium but also more massive teeth and jaws than *Australopithecus*. That there has been a significant increase in the relative height of the neurocranium of *Australopithecus* as compared to pongids and some monkeys has been demonstrated by Ashton and Zuckerman ('51) using the "supraorbital height index" devised by Le Gros Clark ('50), who was the first to point this out. The more advanced crestring condition—in the hominine direction—of *Australopithecus* is in keeping with the fact that in many other respects this form is similarly more advanced than *Paranthropus*.

The central argument advanced here may briefly be summarized as follows:

Throughout the primates the basic crestring process is the same, but nevertheless the australopithecines differ from the pongids in that (a) the australopithecine sagittal crest, when present, does not extend right back to the superior nuchal line and (b) australopithecines do not have a compound (T/N) nuchal crest. These differences are due to the fact that the australopithecine nuchal plane is more nearly horizontal than that of any pongid, thereby moving the nuchal musculature to a position which normally precludes the possibility of their reaching the temporalis muscle. In this feature the australopithecines and the hominines similarly differ from the pongids, in both direction and degree. Both *Australopithecus* (Sts. 5) and the hominines also differ from the usual pongid condition in the relative height of the vault above the upper orbital margin. A trend in this direction — increase of skull size relative to muscle size — militates against the formation of a sagittal crest. It is thus clear that the nature of pre-hominine crestring reflects certain features of skull architecture, and the differences from the pongid condition simply emphasize the fact that the australopithecine skull exhibits trends typical of hominid cranial morphology — trends which do not change but which are simply carried a little further in hominines. If I am correct in attributing changed orientation of the planum nuchale to erect posture, then not only do *Paranthropus* and *Australopithecus* show two structural stages in the change from non-hominid to hominine crestring type, hence skull structure, but they also indicate the major part of the mechanism responsible for the changes. The crestring pattern of the australopithecines thus, far from indicating close relationship to pongids, is simply another of the long series of features which indicate close phylogenetic relationship of these animals to the hominines.

SUMMARY

1. The nature of crests is discussed and distinction made between a torus, a simple crest and a compound crest. A compound crest resulting from the joint action of the tem-

poralis and nuchal muscles, such as that always present in pongids, is referred to as a compound (T/N) nuchal crest.

2. The basic factors determining the development of crests are the same throughout the Mammalia — neither in the pongids nor in the hominids are any new or special factors at work.

3. However, modifying influences, which are discussed, are at work; since the result of the basic crestring process is not the same in pongids and hominids.

4. The crests in the australopithecines have been shown to differ from those in the pongids in that (a) the small partial nuchal crest is not a compound (T/N) nuchal crest, and (b) the sagittal crest, when present, does not extend back to the superior nuchal line.

5. These differences in the crests are reflections of the fact that in australopithecines the nuchal plane is appreciably more horizontal than it is in the pongids.

6. The orientation of the nuchal plane is a character in which hominines and australopithecines agree and differ from pongids. It is submitted that the reason for the changed orientation in the former two groups is erect posture.

7. The *Australopithecus* skull also differs from that of pongids in that the vault rises relatively higher above the upper orbital margin. This feature affects the sagittal crest and is also a trend to be found in the hominines.

8. The differences in the crests of pongids and australopithecines simply reflect differences in skull structure; the australopithecine skull clearly shows trends which are typically hominid and are not changed but merely carried further in hominines.

9. The evidence from the available australopithecine specimens thus demonstrates that the cranial crests of the Australopithecinae did not develop according to the general pattern which prevails in living monkeys and apes. Instead, the australopithecine crestring pattern exhibits fundamental agreement with the hominine pattern and gives insight into the origin of the latter.

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CORONAL DEVIATION AND TILT IN THE PROXIMAL INTERPHALANGEAL JOINTS OF MAN¹

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SEVEN FIGURES

INTRODUCTION

Observation of the digits of the hand will disclose that the more distal part of a digit frequently does not come to lie exactly parallel with the proximal part after full flexion. This divergence of the distal part of a digit is usually more evident in the index and minimus than in the other digits of the hand. Divergence may be the result of conditions at the metacarpophalangeal, the proximal interphalangeal or the distal interphalangeal joints. The present study is an attempt to put on a quantitative basis the conditions at the proximal interphalangeal joint which may contribute to this divergence of the distal part of the digit during flexion.

The proximal interphalangeal joint is considered to have one degree of freedom, i.e., permitting flexion and extension only. A joint with one degree of freedom possesses only one major axis around which the bones rotate. This axis is generally presumed to lie parallel to the medial-lateral axis of the finger joints (fig. 1). However, it is possible that this mechanical axis may not be parallel to the medial-lateral axis, i.e., it may take the position A-X in figure 1 thereby producing the angle

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β . Such a deviation of the mechanical axis of the joint from the medial-lateral anatomical axis occurring in the coronal plane is called coronal deviation. Such coronal deviation could be responsible for all, only part, or none of the divergence observed in the flexed finger.

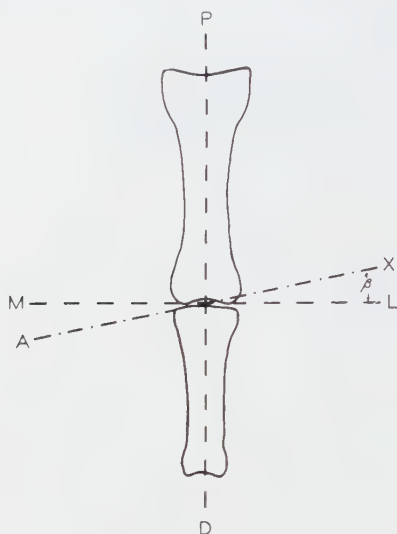


Fig. 1 Diagrammatic representation of the axes associated with the proximal interphalangeal joint. PD = proximal distal axes of the proximal and middle phalanges. ML = medial-lateral anatomical axis. AX = mechanical axis of this joint. This axis may not be parallel with ML; thereby producing the angle β .

Similarly in the horizontal plane the mechanical axis of the joint is generally presumed to be parallel to the medial-lateral axis of the finger (fig. 2). However, it is conceivable that it may not be parallel to the medial-lateral axis but may be at an angle to it, i.e., take the position of A-X in figure 2, thereby producing the angle α . Such a deviation of the mechanical axis of the joint from the medial-lateral anatomical axis, occurring in the anterior-posterior plane, is called tilt.

The present work was undertaken to investigate the movements at the proximal interphalangeal joints of the hand in order to determine the contribution of coronal deviation and

tilt to the observed divergence and to secure quantitative data relative to the magnitude of each.

MATERIALS AND METHODS

An apparatus was devised (fig. 3) to record the divergence of the proximal interphalangeal joints during flexion. A shotgun shell of the proper size was slipped on the finger and carried as far proximal on the middle phalanx as possible without embarrassing the proximal interphalangeal joint. This shotgun shell served a dual purpose. First, it acted as a splint which immobilized the distal interphalangeal joint

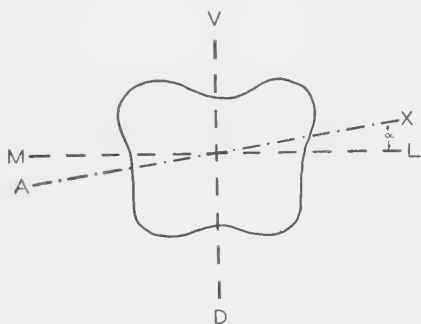


Fig. 2 Diagrammatic representation of the axes associated with the distal end of the proximal phalanx. VD = ventral-dorsal axis, ML = medial-lateral axis. AX = mechanical axis of the joint which in this plane may also not be parallel with ML and thus produce the angle α .

thereby preventing this joint from making a contribution to the results. Secondly, the shell being fitted with a Luer slip, a number 16 needle was attached to serve as an indicator of the movements of the proximal interphalangeal joint.

In order to fix and thereby prevent participation of the joints of the finger and hand proximal to the proximal interphalangeal joint of the finger the following precautions were taken. Plastic strips were applied to the dorsal and palmar surfaces of the hand and bolted together at their ends. These strips fixed the relative positions of the metacarpus so that it could not alter the positions of the phalanges. Fluoroscopic

examination confirmed the fact that this method of clamping did indeed prevent relative motion among the metacarpal bones when the digits were flexed. The metacarpophalangeal joint was immobilized each time by placing the hand in such a position that the head of the metacarpal of the finger in

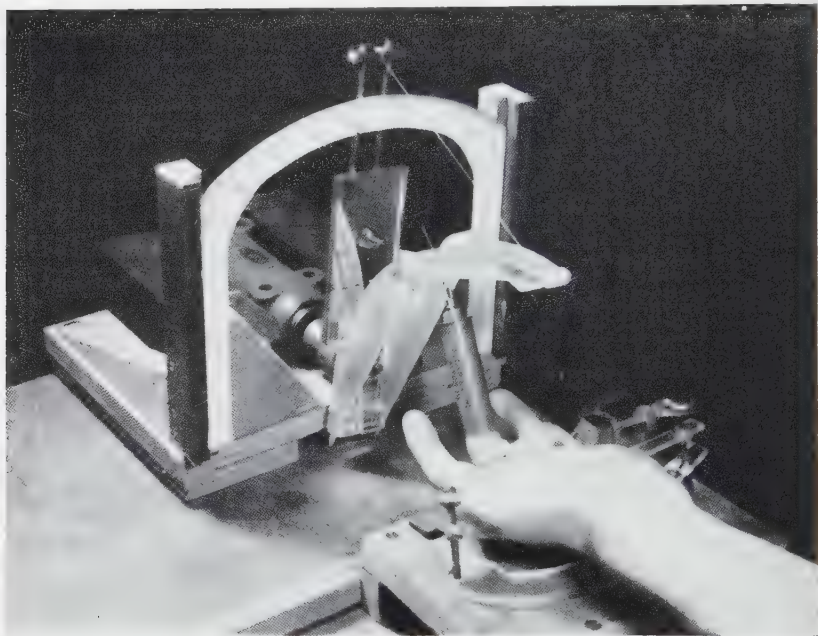


Fig. 3 Photograph of the apparatus used to measure the divergence occurring at the proximal interphalangeal joint.

question was placed in a groove on a movable table. Distal to this groove was an adjustable clamp which closed on the proximal phalanx and immobilized it. The table carrying the groove and the adjustable clamp was always oriented at a fixed distance away from and at right angles to the main axis of the recording apparatus. These precautions assured that the joint to be measured was in each case in the same relative position in regard to the metacarpus as well as to the recording apparatus.

In order to measure the divergence, two quarter circles of plastic with a 5-mm space between were mounted to the end of a freely movable balanced shaft. The space between the quarter circles accommodated the pointer carried by the shotgun shell. A device was mounted on the shaft to carry a hair line perpendicular to the shaft and parallel to the center of the slot in the quarter circle. A 14" protractor was mounted in front of the hair line from which the amount of divergence was read in degrees. The quarter circle of plastic was calibrated in 10° intervals from 0° to 90° so that the amount of flexion of the joint was evident at all times. A mirror was mounted on the hair line carrier so that the subject could see the graduations on the plastic quarter circle and flex the finger the required amount.

The geometry of this system was such that, for a perfect pin joint, the number of degrees by which the shaft was rotated was equal to a constant (T) plus the sine^{-1} of a constant (CD) times the tangent of one half the degrees of flexion. Because of the small number of degrees involved, this equation is accurately represented by the approximation: degrees of rotation equals T plus CD times the tangent of one half the degrees of flexion. The constant T has been defined as the tilt and CD as the coronal deviation. Hence the tilt (angle α in fig. 2) is the number of degrees by which the axis of the joint has been rotated about the long axis of the proximal phalanx. The coronal deviation (angle β in fig. 1) is the number of degrees by which the axis of rotation has been deflected to the radial or ulnar side in a coronal plane. The signs of these variables have been chosen as positive if they represent a divergence of the distal two phalanges in a radial direction.

By using the methods and apparatus described above, the divergence at the proximal interphalangeal joints of the index, medius, anularis and minimus of both the right and left hands of 40 white, male, right-handed medical students between the ages of 21 and 29 years, was measured.

RESULTS

The readings made from the series of subjects showed wide variation and many individual peculiarities. In order to compare the readings from one subject with those of another, the data were all reduced in terms of the medius of the hand in question and the various hands compared in terms of their variations from their own medii. In order to substantiate this approach, an analysis of the type and direction of the divergence of the digits from the medius was made.

A typical set of readings is indicated in table 1. It will be noted that the medius showed no measurable divergence until a flexion of 70° was attained. As will be subsequently shown, the medius and anularis are very similar in this regard and either finger would serve equally well as a comparitor or common denominator. The medius was arbitrarily selected.

The geometry of the apparatus was demonstrated and verified by making a series of measurements in the apparatus with a pin joint. It was found that tilt alone produced a straight line parallel with the abscissa while coronal deviation produced a curve whose slope increased with the degree of flexion. These effects were additive (fig. 4).

As shown in A (fig. 5), the typical medius (dotted line) produced a curve which left the abscissa at 60° and continued upward until 90° . At this point 3° of deflection was recorded. Such a curve indicates that the divergence seen in the medius is due to a combination of coronal deviation and tilt. The curve produced by an actual pin joint which comes near to fitting the curve of the medius is represented by the solid line. The tilt and coronal deviation of the theoretical curve are -1 and 4 respectively.

The recorded movements of this particular medius indicate that the action occurring at the proximal interphalangeal joint is very similar to that of a pin joint having both coronal deviation and tilt, but the identity is not absolute. The small magnitude of the difference between the proximal interphalangeal joint and a pin joint is indicated by B (fig. 5) (solid line) in which the greatest difference is shown to be 1° at

TABLE 1
Typical divergence readings, subject no. 38, left hand

DEGREES OF FLEXION	INDEX		MEDIUS		ANULARIS		MINIMUS	
	Raw	Adj.	Raw	Adj.	Raw	Adj.	Raw	Adj.
20°	- 0.75°	- 0.75°	0.00°	0.00°	0.00°	0.00°	0.50°	0.50°
30°	- 1.50°	- 1.50°	0.00°	0.00°	- 1.00°	- 1.00°	2.00°	2.00°
40°	- 1.75°	- 1.75°	0.00°	0.00°	- 1.00°	- 1.00°	3.00°	3.00°
50°	- 1.25°	- 1.25°	0.00°	0.00°	- 1.00°	- 1.00°	3.75°	3.75°
60°	- 1.00°	- 1.00°	0.00°	0.00°	- 1.25°	- 1.25°	5.50°	5.50°
70°	- 0.75°	- 1.50°	0.75°	0.00°	- 1.00°	- 1.75°	6.25°	5.50°
80°	- 0.50°	- 2.25°	1.75°	0.00°	- 1.00°	- 2.75°	7.75°	6.00°
90°	0.00°	- 2.50°	2.50°	0.00°	- 0.75°	- 3.25°	8.50°	6.00°

60° of flexion while at other values for flexion the disparity is even less. That this small magnitude of difference is a constant feature of the medius is shown by C (fig. 5) where the averages of the differences between the theoretical and actual curves for the 10 most extreme cases are graphically

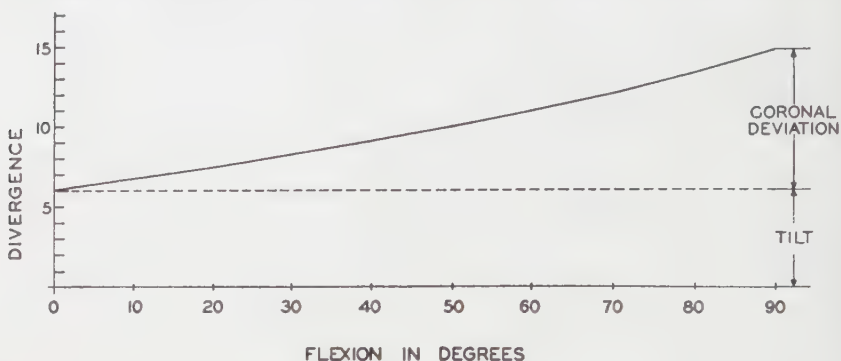


Fig. 4 Graphic representation of the curves produced in a pin joint with a tilt of 6° and a coronal deviation of 9°.

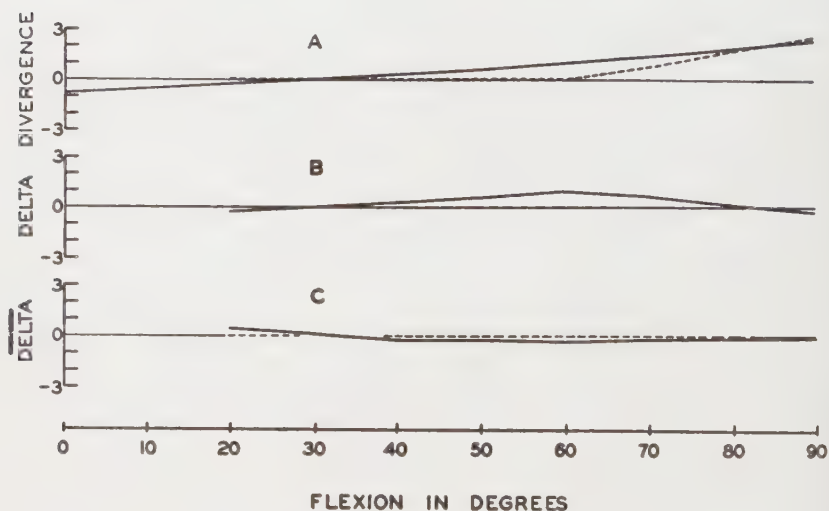


Fig. 5 A, The dotted line represents the curve produced by a medius with 3° divergence. The solid line represents the curve produced by a true pin joint. B, Graphic representation of the difference (Delta) between the curve produced by a pin joint and the proximal interphalangeal joint. C, Graphic representation of the average difference (Delta) between the theoretical pin joint and the actual medius measurements in the 10 most extreme cases.

presented. The average disparity between the proximal interphalangeal joint and a pin joint was found to be less than 0.3° .

This slight disparity was ignored and for purposes of reference the medius was assumed to be a pin joint which could be oriented so that its coronal deviation and tilt were zero. Therefore, after sets of readings had been taken for each of the digits, the values for the medius of that hand were subtracted from the values of the index, anularis and minimus of the same hand.

This is geometrically equivalent to orienting the hand in such a way that the tilt and coronal deviation of the medius are exactly zero. Thus in figure 6, which is a plot of such

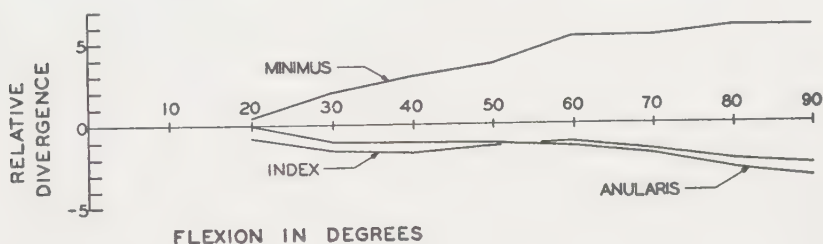


Fig. 6 Divergence curves produced by a single set of readings.

reduced readings for a typical hand, the medius would be represented by a straight line superimposed on the abscissa. The signs for both coronal deviation and tilt were so chosen that each is positive if it produces deflection of the distal phalanges towards the radial side of the hand; negative if toward the ulnar side of the hand. It can be seen in this figure that relative to the medius the index and anularis move in an ulnar direction (indicated by negative values) while the minimus moves radialward (indicated by positive values). For this particular hand the anularis had approximately the same coronal deviation and tilt as did the index. It has been shown earlier that such divergence in the actions of the fingers can be attributed almost entirely to varying degrees of coronal deviation and tilt in the joints under discussion. For example, the set of readings depicted for the minimus in figure 6 were produced by a tilt of approximately -2° and a

coronal deviation of about 8° . Thus for this hand the tilt of the minimus produces a more ulnarward deflection than does that of the medius while the coronal deviation of the minimus causes that digit to move more radially than does that of the medius. What is seen in actual practice is the resultant of these two opposing deflections, i.e., a net deflection in a more radialward direction than is produced by the medius.

DISCUSSION

This study has placed on a quantitative basis the amount of divergence of a digit distal to the proximal interphalangeal joint. The divergence that occurs at this joint is apparently due to the mechanical axis not being parallel to the medial-lateral axis in the coronal plane (coronal deviation) or to the mechanical axis not being parallel to the medial-lateral axis of the finger in the horizontal plane (tilt).

The mean values of the measurements of the right and left hands of 40 subjects are graphically presented in figure 7. The largest amount of divergence was found in the left minimus and the smallest amount was found in the anularis and medius. Upon analysis of the divergence (table 2) it is evident that all of the values for tilt are extremely small and fall within the error of the technique and the type of apparatus used. It appears then that the major factor in divergence is coronal deviation.

The divergence that occurs at the proximal interphalangeal joint of the right index finger was in an ulnar direction. The divergence that occurs in the left index finger is also in an ulnar direction but is less in amount. The right index finger showed a mean tilt of only -0.22° . The deflection of the distal part of this finger in an ulnar direction was due, therefore, to the -3.5° coronal deviation. However, the left index finger showed only a small amount of divergence and this may be due to the sample being made up only of right handed individuals. It may be that divergence at the proximal interphalangeal joint is associated with the handedness of the individual. If this is so one would expect to find a greater divergence in the proximal interphalangeal joint of the left index finger of left handed individuals.

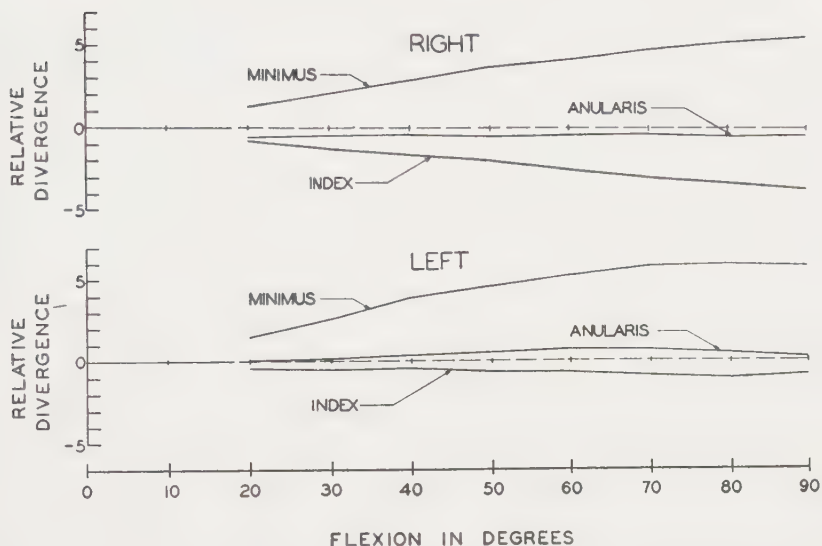


Fig. 7 The average divergence curves produced by readings made on the proximal interphalangeal joints of 40 right and 40 left hands.

The divergence occurring at the proximal interphalangeal joints of the right anularis is extremely slight and has a negative sign. The left anularis, although again showing only slight divergence, moves toward the positive side. There is no measurable coronal deviation and a very small amount of tilt in the proximal interphalangeal joint of this finger. As was pointed out earlier, this finger does not differ appreciably in divergence from the medius.

The minimus of the right hand exhibited a greater amount of divergence than any of the other fingers of the right hand and the minimus of the left hand exhibited a greater amount of divergence than any of the other fingers of the left hand.

TABLE 2

Analysis of divergence of forty subjects

	INDEX		ANULARIS		MINIMUS	
	R	L	R	L	R	L
Tilt	— .22	— .20	— .48	— .21	.94	1.8
Coronal deviation	— 3.5	— .50	0	0	4.7	4.2

This divergence in both hands was in a positive direction, that is, toward the radial side of the hand. The divergence of the minimus was due to the large amount of coronal deviation at the proximal interphalangeal joint of this finger (table 2). These values were greater than for any other finger measured.

From these data it is evident that tilt as illustrated in figure 2 plays a relatively minor role in the divergence seen at the proximal interphalangeal joint, and that the mechanical axis of the joint is very nearly parallel to the medial-lateral axis of the finger in the horizontal plane. In the coronal plane, the data indicate that the axis of the joint is not parallel to the medial-lateral axis of the finger and that this circumstance is responsible for the divergence at the proximal interphalangeal joint.

SUMMARY

An apparatus was devised to record the divergence at the proximal interphalangeal joint in the human hand. Such divergence was measured in the hands of 40 white, right-handed, male students between the ages of 21 and 29.

The divergence of the proximal interphalangeal joint of the medius was negligible and the divergence of the other fingers was analyzed in terms of the medius of the hand in question.

The recorded divergence was interpreted to be the result of the deviation of the mechanical axis of the joint from the anatomical axis. This deviation in a coronal plane was designated as coronal deviation and in a horizontal plane as tilt.

The results of the study indicate that tilt plays a negligible role and that the divergence at the proximal interphalangeal joint is due to coronal deviation. The proximal interphalangeal joint of the anularis of the right and of the left hand showed no coronal deviation, while the index showed measurable amounts and the minimus produced the greatest values. Slight differences in the amount of coronal deviation between the right and left hands were to be seen only in the index finger.

THE SKELETON OF
PLIOPITHECUS (EPIPLIOPITHECUS)
VINDOBONENSIS ZAPFE AND HÜRZELER

HELMUTH ZAPFE

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FOUR FIGURES

The primate material to be discussed in this report is from Neudorf on the March River in Czechoslovakia. Two preliminary papers have already been published concerning these discoveries (Zapfe, '52; Zapfe and Hürzeler, '57). The research on the skeletons was completed at the American Museum of Natural History, New York, in 1958 and the results of that study are contained in this report.

The material was found in a fissure deposit in a stone quarry near Neudorf (Nova Ves) in the most southern part of the Carpathian Mountains on the eastern border of the Vienna basin. The rock is a gray limestone and dolomite of Mesozoic, perhaps Jurassic, age. The fissure deposit consists of rust-brown or reddish clay with pieces of limestone of various sizes. The bones were found in the clay between the limestone blocks. The skeletal remains of the most completely preserved individual were found scattered on the inclined surface of a big limestone block. The stratigraphic position of the fissure deposit can be dated precisely. On the slope above the quarry at the time of discovery could be seen traces of the marine deposits of the middle Miocene (Tortonian) overlying the fissure fillings. The fissure deposit must be older than Tortonian. The fauna (about 60 species, mostly mammals) which accompanies the primates, however, excludes the possibility of a lower Miocene age. Therefore, Helvetian, or lower middle Miocene is the only remaining choice. It is seldom that a terrestrial fis-

sure deposit can be dated so precisely (Zapfe, '53). The remains represent the skeletons of three individuals (I, II, III), and some isolated bones of other individuals. The dentition and nearly all bones of the skeleton are represented except for the occipital region and the base of the skull. Also unknown are different vertebrae and ribs, some tarsal and carpal bones, some phalanges and parts of the fibula and pelvis.

Skull and dentition

Dentition. The teeth (figs. 1, 2) are similar in the majority of characters to those of *Pliopithecus antiquus*, whose odontology was described by Hürzeler ('54) in detail. The small differences present are mostly in the upper teeth (fig. 2). The third upper molar is rather large. The cingulum is especially pronounced and in the individual figured (III) it envelops the hypocone. One might consider this hypocone as a pseudo-hypocone and not recognize it as a derivative of the cingulum. However, the form of the cingulum varies and in the upper molars of another individual (II) it is much less strongly developed. The most significant difference in the upper teeth is the groove in the cingulum on the labial side of the first incisor. Hürzeler has never found such a groove on any of several known incisors of *Pliopithecus antiquus*. One must consider indeed that this characteristic would be clearly observable only in unworn teeth. The lower dentition clearly differs from *Pliopithecus antiquus* in only one respect: The connecting line from the protoconid to hypoconulid is practically straight in the second lower molar or even in the third. The hypoconulid is situated on the labial side, especially in the third lower molar, in contrast to *Pliopithecus antiquus*. Hürzeler and the author have collaborated on an article concerning these features. We do not agree as to the significance of these differences. Hürzeler considered them to be sufficiently important to warrant erecting a new genus, *Epiplio-pithecus*. Zapfe considers the majority of these differences insignificant in view of the variability of teeth in living anthro-

poids. The only true difference may be the shape of the cingulum of the upper medial incisor, but Zapfe does not believe this difference constitutes sufficient basis for the establishment of a new genus. Apart from that, practically speaking, it would be very inconvenient in the future to have to rely exclusively on the first incisor for generic identification. Furthermore, one must consider that the upper dentition of the type species, *Pliopithecus antiquus* (Blainville), from Sansan, France, is itself unknown. For these reasons it would seem wiser at present to refer these specimens to the genus *Pliopithecus* and to differentiate them only as a new subgenus and species (Zapfe and Hürzeler, '57).

Skull. The facial part of the skull of individual II is preserved. In both figured views the skull is oriented in the Frankfort horizontal (fig. 3). The most important features of the skull are the following: The remarkably small width of the snout, similar to *Hylobates moloch* and langurs; and the large interorbital distance, as in platyrrhines and anthropoids. As a fragment of another individual (III) indicates, the nasal aperture narrows toward its base, as in cynomorphs. The *os zygomaticum* is steeply bent posteriorly. The prognathism is clearly shown. The facial index is similar to that of monkeys and *Hylobates*. There is no sagittal crest in the skull of individual II (fig. 3A). The low temporal crests extend higher up on the frontals, approach each other and posteriorly appear to diverge again. In a skull fragment of individual III the temporal lines join to form a low median sagittal crest. Just

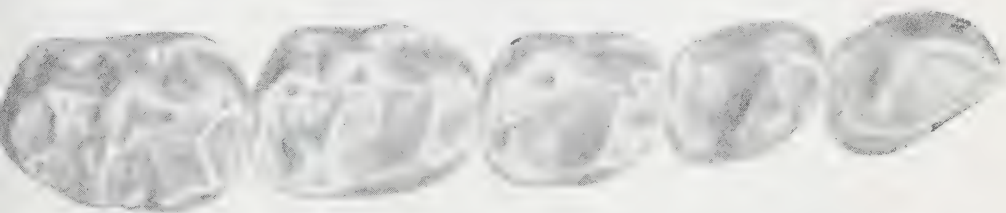


Fig. 1 *Pliopithecus* (*Epipliopithecus*) *vindobonensis* Zapfe and Hürzeler, middle Miocene (Helvetian) fissure deposit from Neudorf (Nova Ves), on the March River, Czechoslovakia. Left mandibular dentition of individual II. $\times 4$.



Fig. 2 Left maxillary dentition of individual III (holotype) with broken second incisor. $\times 4$. (after Zapfe and Hürzeler, '57).

in front of the occipital suture they separate to the left and right forming a marked occipital crest. Thus, variability, similar to the conditions observed in certain platyrrhines, is shown in the formation of the crests. In male *Cebus* skulls separate temporal lines and also a low sagittal crest are found. *Pliopithecus* demonstrates a similar stage of the loss of the sagittal crest as in the platyrrhines, and the hylobatids, a low sagittal crest seldom appearing in the siamang (Schultz, '33).

The auditory region of the skull is rather well preserved as isolated fragments in individuals II and III. The most notable characteristic is the extremely short external auditory meatus which is deeply notched on the lower side so that it is divided into two granular projections. This condition is apparently representative of a primitive stage of development of the bony auditory meatus of the catarrhines. The endocranial surface shows a large arcuate fossa in individual II, and a tendency toward reduction and closing of the fossa in individual III. The open arcuate fossa is a primitive characteristic also present in monkeys and in *Hylobates*. The right incus was recovered from individual II. In form it is very similar to that of recent cynomorphs. The auditory region is exceedingly primitive, so much so that if it had been found alone, dissociated from the rest of the skeleton, it would not have been assigned to a fossil anthropoid.

The mandibles of individuals I, II and III have been found. Characters to be noted are the steeply ascendant ramus and the angle formed by the tooth rows—a primitive feature. There is no “simian shelf.”

Postcranial skeleton

Vertebral column. Single vertebrae are preserved of all three individuals. Particularly interesting is a complex of three lumbar vertebrae (3., 5., 6.) and the first sacral vertebra of individual II. A study of the vertebrae shows that *Pliopithecus* had at least 6 and probably 7 lumbar vertebrae. Schultz ('38) compounded a formula for the relationship of the ver-

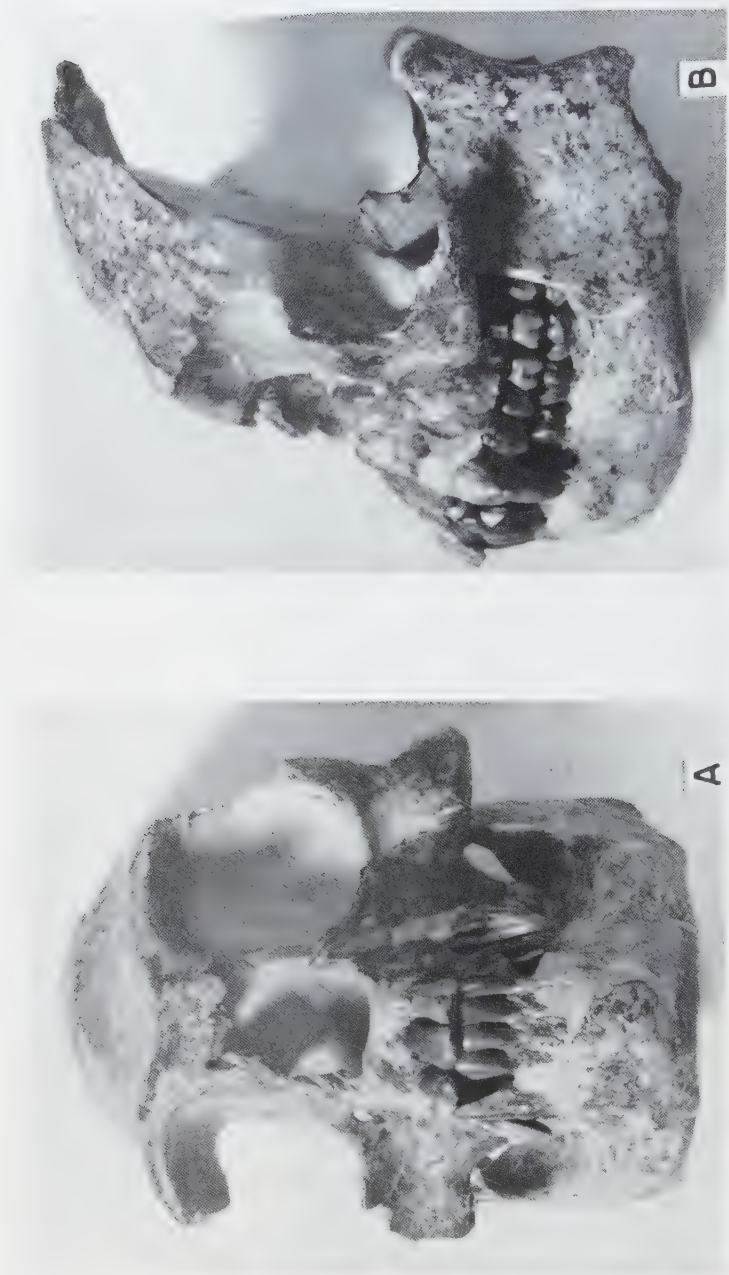


Fig. 3. *Platipithecus (Epiplatipithecus) vindobonensis* Zapfe and Hürzeler, skull of individual II. A, Anterior view. B, Left lateral view. (about natural size).

tebrae whereby the length of the lumbar column and the whole vertebral column can be calculated from the average length of the lumbar segments. It will be shown that *Pliopithecus* is primitive in the majority of skeletal characters. This is particularly true of the proportions of the skeleton which are similar to those of monkeys. Therefore it is possible to use the numerical relationship of the monkeys in an estimate of the length of the vertebral column and the lumbar vertebral column, which agrees well with the presence of 7 lumbar vertebrae. Also worthy of mention is the relatively great length of the bodies of the lumbar vertebrae, which entirely correspond in their proportions to those of the monkeys. Of particular importance is the complete sacrum of individual I, consisting of only three sacral vertebrae. This form is similar to that of monkeys. Three caudal vertebrae may be assumed. *Pliopithecus* was tailless. The construction of the vertebral column may be summarized as follows: 7 cervical vertebrae, 12 to 13? thoracic vertebrae, 6 to 7? lumbar vertebrae, 3 sacral vertebrae, 3 caudal vertebrae.

Shoulder girdle. The clavicle (individuals I and III) and the sternum (individual II) are almost complete. The clavicle is moderately curved to the sigmoid. The sternal end is flattened. The bony tubercle for the conoid ligament is well developed. The two clavicles vary considerably in detail. Taken as a whole the clavicle might be considered anthropoid. There are, however, similarities to the chimpanzee, female gorillas and man, whereas such a clavicle is found only infrequently among the monkeys. The claviculo-humeral index is remarkably anthropoid. The sternum is complete, only the manubrium is lacking. The width and the flattened form of the sternum are chiefly anthropoid, but also occur in some platyrrhines. The length-width index is very close to that of anthropoids and some platyrrhines. The number of 5 segments and the probable 8 sternal rib pairs are primitive and reminiscent of the monkeys. Only that part around the glenoid fossa of the scapula is preserved. The long-oval outline of the fossa is primitive and similar to that of some platyrrhines and prosimians.

Pelvic girdle. A straight fragment of the ilium is preserved from individual II. It is in all features similar to the ilium of monkeys. In particular the presence of a low anterior inferior iliac spine should be mentioned. In the preliminary paper (Zapfe, '52) about this primate discovery the primitive character of this fragment had not been recognized and must be corrected here. The monkey-like form of the sacrum has been described above. Thus, in the pelvic girdle primitive characteristics prevail, while in the shoulder girdle some anthropoid tendencies are present.

Humerus. The humerus, completely preserved in individual II, is primitive in its general form and has some noteworthy similarities to the prosimians (for example, *Propithecus*). The most important features are as follows: the head reaches over the *tuberculum majus* as in prosimians, platyrrhines, anthropoids and man. The intertubercular sulcus is wide and shallow as in the cynomorphs, most platyrrhines and prosimians. A definite delto-pectoral crest is lacking as is the case among some platyrrhines, all anthropoids and man. A straight staff-like shaft without any strong curvature is present as in prosimians, platyrrhines, hylobatids and very similar to man. The strong supinator crest is developed as among most prosimians, some non-brachiating platyrrhines, and is similar to the chimpanzee. The entepicondylar foramen is present as in prosimians, some non-brachiating platyrrhines and in exceptional cases in man. The shallow olecranon fossa with triangular shape recalls the prosimians and platyrrhines. On the flat, broad distal end the trochlea is shorter than the capitulum and has a low lateral edge as in prosimians and platyrrhines. The torsion is relatively small (121°) and is similar to hylobatids, monkeys and prosimians. Most of these characters show the great similarity to the platyrrhines and prosimians.

Ulna. The ulna is completely preserved from both individuals I and II. The most striking features similar to platyrrhines and prosimians are the recognizably large size of the olecranon, the slight downward direction of the coronoid pro-

cess, and the curvature of the smooth shaft. The shape of the tuberosity agrees well with that of many platyrrhines and is similar to that of the hylobatids. The styloid process is long and slender and projects somewhat posteriorly. On the other hand the capitulum is small. This condition is similar to that found among some platyrrhines (*Alouatta*) and is also similar to some cynomorphs (*Papio*). In summary the ulna is very primitive and similarities to the platyrrhines and some prosimians prevail.

Radius. Two complete radii are preserved (individuals I and II). Certain characters are particularly noteworthy. The slender form generally agrees well with various platyrrhines, in particular *Alouatta*, but it also recalls the anthropoids. A comparison of the index of robusticity gives the same picture. The capitulum has no equal rounded border as is found among the anthropoids. The marginal lip is strongest at the articulation with the ulna and is thinnest on the opposite side. The surface of the capitulum is clearly inclined towards the axis of the shaft. This condition is similar to those of monkeys and prosimians. The cross section of the shaft is circular and sharp edges and crests are lacking as in platyrrhines and hylobatids. The distal end is characterized by an elongate ridge for the brachio-radialis muscle, which most closely agrees with the conditions found in *Alouatta*. The semilunar notch is not an indentation, but a somewhat elevated flat facet. This condition agrees best with platyrrhines and cynomorphs. In summary, the radius has characters predominantly in common with modern monkeys. A particular similarity to *Alouatta* is to be observed.

Hand. All metacarpals (except the distal part of metacarpal V) and several phalanges are preserved. Most of the phalanges and metacarpals II, III, IV and V preserved are from the left hand of the same individual (III). The most striking character of the hand is the shortness of the metacarpals. The form of the metacarpals is monkey-like. Also an unciforme (individual III), a lunare and a trapezium (individual II) show conditions similar to those of monkeys, while

the radiale (individuals II and III) is similar to that of the anthropoids. The phalanges are not as flattened as in living anthropoids and it is difficult to distinguish them from the phalanges of the foot. These conditions are found to be typical of the monkeys. The hand as a whole is primitive and similar to that of platyrrhines and some cynomorphs.

Femur. Three complete femora (individuals I and II) and several isolated fragments are preserved. The following are the most important characters noted. A slender staff-like shaft is present as in hylobatids, many platyrrhines and prosimians. The head projects over the great trochanter as among most anthropomorphs and platyrrhines. As in some platyrrhines, a third trochanter is suggested in several individuals. The collo-corpus angle is similar to that of the hylobatids and prosimians and agrees with that of some platyrrhines. The relative size of the medial and lateral condyles is similar to that of the monkeys (except *Ateles*), prosimians, and man. The index of robusticity resembles that of the hylobatids, platyrrhines and many prosimians. Of special importance is a tubercle on the posterior side of the neck which is found in all known femora of fossil anthropoids. It is rather frequent in living and fossil platyrrhines and some living cynomorphs. Le Gros Clark and Leakey ('51) described this tubercle in detail for *Proconsul*. They believed that it has a function in jumping and is not strongly developed among purely arboreal types. To summarize, the shape of the femur is markedly similar to that of hylobatids and platyrrhines. Some features recall the conditions of prosimians.

Patella. Both patellae of individual II are preserved. The patella has approximately a circular outline and is relatively thin. When compared with available material, it agrees perfectly with the patella of *Hylobates moloch*. This agreement is demonstrated in the most important indices. The patella, therefore, as well as the broad shallow patellar facies of the femur, is quite similar to *Hylobates*.

Tibia. Two tibiae, one of these belonging to individual I, are well preserved. The shaft is straight and slender and lacks

sharp crests. The proximal epiphysis has a circular or nearly rounded triangular outline, as among most monkeys and prosimians. The outline of the distal epiphysis is subquadrate, similar to *Hylobates*, most monkeys and man. A narrow extension of the distal surface of the joint extends over the anterior side of the epiphysis. When the joint is flexed for jumping, this surface hits against a delimiting projection on the neck of the talus. Le Gros Clark ('52) believes this feature particularly significant (a "cercopithecoid character"). The peroneal notch is deep and shows no marked facet for the fibula. The notch is similarly formed among many cynomorphs (*Papio*) as well as in man. Although the tibia is a skeletal element which does not vary greatly in primates, the predominance of primitive characters is to be seen. Similarities to the monkeys predominate, while a few anthropoid tendencies appear.

Fibula. Only a small piece of the shaft of the fibula of individual II is preserved. The few points of reference which can be obtained from examination of the edges indicate characters similar to those of the tibia.

Foot. Astragalus (individual I), calcaneum, all metatarsals (individual II) and many phalanges (mostly individual II) are preserved.

Astragalus. The high narrow trochlea is anthropoid and particularly similar to that of hylobatids. The length of the neck resembles the condition in hylobatids and in some monkeys. The long facet for the sustentaculum is monkey-like. The basin-shaped concave facet for the articulation of the malleolus of the tibia and the dorsal tubercle on the neck are cynomorphic. Le Gros Clark and Leakey ('51, p. 88) take this to be a delimiting process of the ankle joint during extreme dorsiflexion. This condition is particularly marked among quadrupedal walking cynomorphs and is absent in nearly all brachiating apes.

Calcaneum. Particularly noteworthy are the strong plantar and peroneal processes. In these characters and some proportions a clear anthropoid component may be recognized. Simi-

larities to *Hylobates* are clear as well as some resemblances to monkeys.

Metatarsals. The most important feature of these slender bones is their relative length. They are remarkably longer than the metacarpals. This proportion is found in monkeys, prosimians and man. The form of the metatarsals resembles that of monkeys (platyrrhines) and in some respects of hylobatids.

Phalanges. Similarities to hylobatids are significant. In addition resemblances to monkeys and prosimians can be recognized. Very probably the digital formula in the hand and foot was III, IV, II, V, I (Midlo, '35). As a whole the foot shows remarkably anthropoid features and some resemblances to monkeys (platyrrhines).

Body proportions and probable mode of locomotion. In studying the body proportions, numerous indices were calculated. The final work on the material and the consideration of the newest literature brought about a new basis for many of these calculations. Therefore, the results often do not agree with the first preliminary report (Zapfe, '52). Most indices agree closely with, or are similar, to those indices in *Papio*, *Macaca* and *Cercopithecus*. One such example is the inter-membral index (table 1). The index for *Pliopithecus* falls within the range of variation for *Papio*, *Macaca* and *Cercopithecus*. Plate 1 shows the limb bones of *Pliopithecus* (a-c) in comparison with a *Hylobates* (d-e) of similar size. The hind legs are of nearly equal length. The prolongation of the forelimb of a recent brachiating ape is impressively shown.

It seems probable that *Pliopithecus* was not entirely arboreal, but also moved about on the ground in the manner of some recent cynomorphs. Support for this belief is also provided by the fact that these skeletal remains were found in a fissure deposit together with other animals which had dropped into this fossil trap. The individuals of *Pliopithecus* could hardly ever have gotten into the Neudorf fissure if they had not been moving about on the ground or climbed down into the fissure (Zapfe, '56). The same holds true, by the way,

TABLE 1

*Intermembral index**All indices of living primates and man after Mollison, '11*

SPECIES	SPECIMENS	AVERAGE	MIN. AND MAX.
<i>Pliopithecus</i> (<i>Epipliopithecus</i>) <i>vindobonensis</i>	1	94.1	94.1
<i>Lemur catta</i>	3	67.7	66-69
<i>Lemur macaco</i>	4	72.0	70-77
<i>Nycticebus tardigradus</i>	6	89.0	84-93
<i>Callithrix jacchus</i>	12	74.5	71-77
<i>Cebus flavus</i>	1	86	86
<i>Ateles hybridus</i>	1	101	101
<i>Papio cynocephalus</i>	7	89.4	86-94
<i>Papio hamadryas</i>	11	96.7	93-99
<i>Macaca nemestrina</i>	9	90.9	83-97
<i>Macaca fascicularis</i>	20	90.8	85-93
<i>Cercopithecus callitrichus</i>	12	83.7	75-95
<i>Cercopithecus sabaens</i>	5	82.8	80-84
Gibbon	29	144.5	134-152
Orang-utan	6	143.8	138-150
Gorilla	2	118.5	116-121
Chimpanzee	9	109.0	105-113
Man	100	73.2	65-81

for the discoveries in coal deposits of *Oreopithecus* and several Miocene anthropoids (for example, *Pliopithecus antiquus* in the middle Miocene coal of Göriach, Styria, and *Dryopithecus* in the upper Miocene coal of St. Stefan, Carinthia, Austria). Here too are animals, which sank and were buried in the bog upon which they must have moved about. In this way it seems possible to conclude the mode of locomotion by the nature of the fossil occurrence.

SUMMARY

The skeleton of *Pliopithecus* (*Epipliopithecus*) *vindobonensis* is one of the best preserved fossil anthropoids known. This exceptional preservation of these skeletal remains from the Vienna Basin deserves emphasis. For the first time it has been possible to study the dentition, the skull and all other

important skeletal elements and proportions of a Miocene anthropoid, and as a result, to ascertain that an anthropoid dentition does as a matter of fact belong to a skeleton of predominantly primitive characteristics. Prior to this discovery, it was highly unlikely, to say the least, that this humerus or auditory region would have been recognized and properly identified as anthropoid remains.

ACKNOWLEDGMENTS

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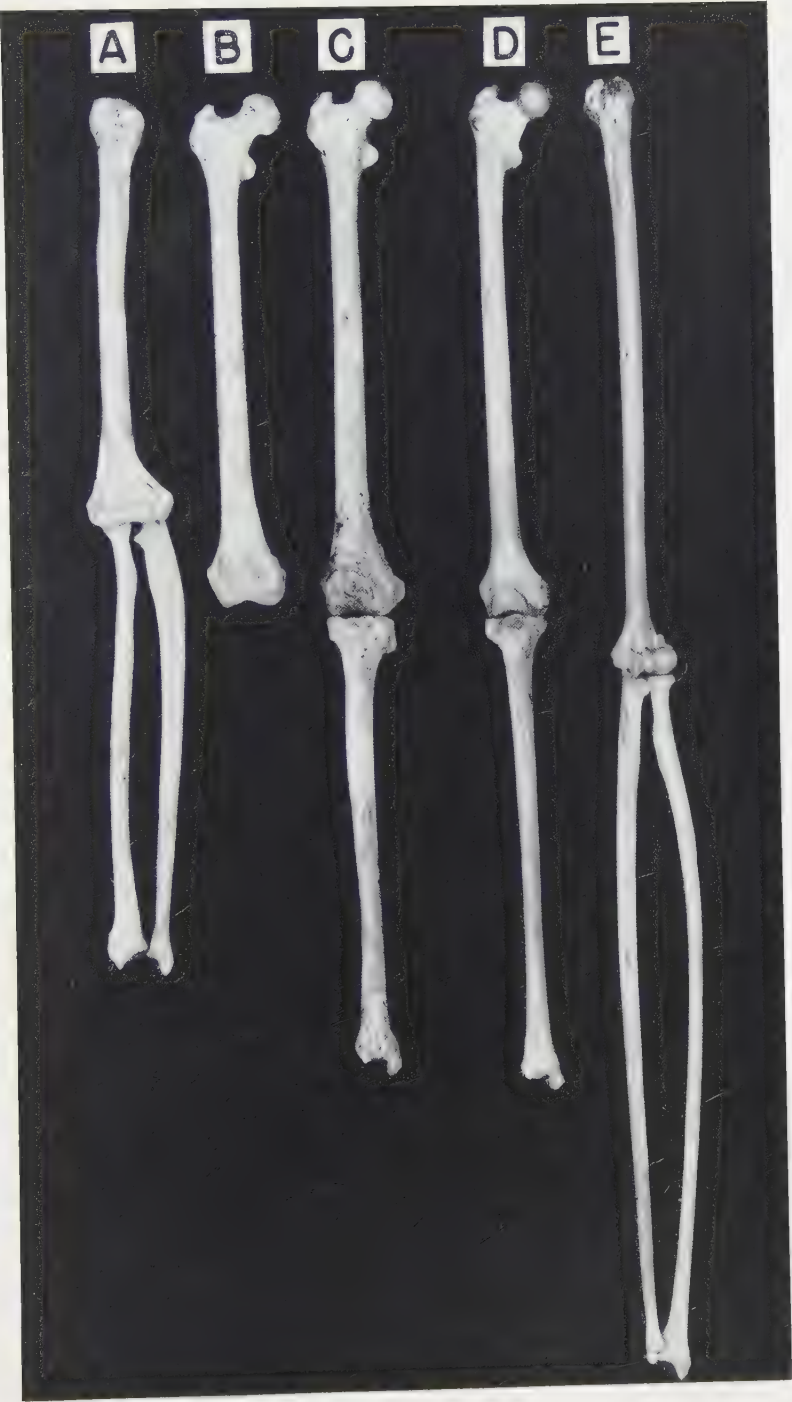
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PLATE 1

EXPLANATION OF FIGURES

- 4 *Pliopithecus* (*Epipliopithecus*) *vindobonensis* Zapfe and Hürzeler. (About natural size.) A, Right forelimb (humerus, ulna, and radius) of individual II. B, Right femur of individual II. C, Right femur and tibia of individual I. D, Right hind limb of *Hylobates*. E, Left forelimb of *Hylobates*.





TZEYANG PALEOLITHIC MAN — EARLIEST REPRESENTATIVE OF MODERN MAN IN CHINA

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THREE FIGURES

During the reconstruction of the Chengtu-Chungking Railway in 1951, workers, in digging the foundations for a bridge crossing the river Huangshanchi in Tzeyang District, Szechuan Province, discovered many mammalian fossils, including one human skull in a layer of sand and pebbles about 7–8 meters below the land surface. Associated with the skull was an awl made of bone splinter. A great number of fossil trees and leaves of various plants were also collected. Highly interested by these finds, the former Geological Directing Committee of China sent Dr. Pei Wen-chung to Tzeyang to survey the site.

The site of Tzeyang

The fossiliferous locality is situated about $\frac{1}{2}$ km west of the Tzeyang City. A section of the site, made by Dr. Pei, is shown in figure 1. The upper part of the section consists of a layer of yellowish red clay about 6 meters in average thickness. Underneath is a layer of dark gray clay, containing a large number of decayed organisms and some thin layers of fine sand. The third layer is composed of yellowish sand and small pebbles from 1 to 1.5 meters thick containing remains of big trees and few fossil bones. It is reported that the fossil human skull was unearthed from this layer. In the lower part of this layer, the sand became coarser and pebbles

larger, fossil bones were all fragmentary and rolled, and fossil trees were rare. In the fourth layer, the pebbles gradually increased to gravel size, and the amount of sand diminished; no fossil bones or fossil trees were found.

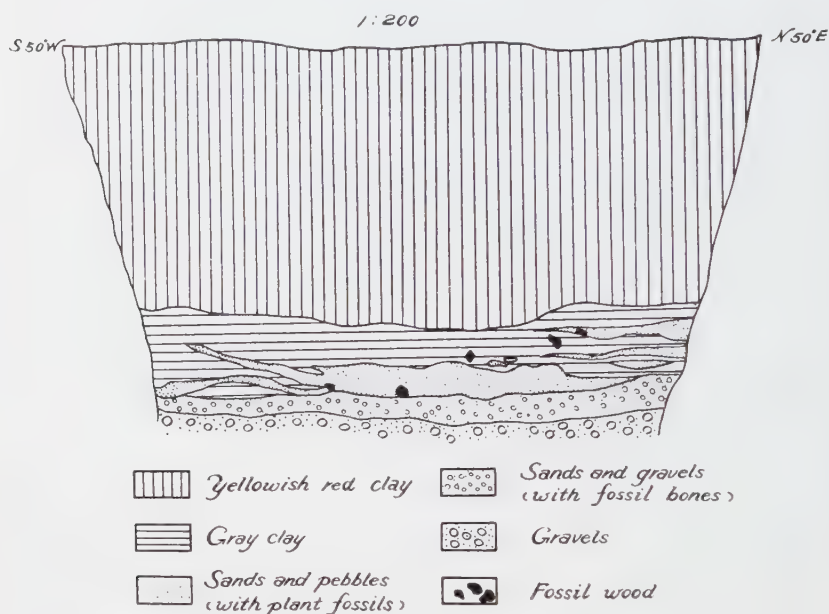


Fig. 1 Vertical section of the Tzeyang site (after Pei).

The fauna

Fossil mammalian bones collected from Tzeyang are classified by Pei into two groups. One is of Late Pleistocene age, including *Homo sapiens*, *Equus* sp., *Muntiacus reevesi*, ? *Mochus* and *Mammonteus primigenius*. All are lightly fossilized, not worn by water and contain small percentages of fluorine.

The second group, of Middle Pleistocene age, includes remains of *Stegodon orientalis*, *Cervus* (*Rusa*) *unicolor* and *Rhinoceros sinensis*. All are strongly mineralized, water-rolled and contain greater fluorine percentages.

Hyaena sp., *Felis tigris*, *Sus* sp., *Hystrix* sp. and *Rhizomys* sp. are perhaps present in both groups.

The industry

The only artifact discovered in the third layer was a bone awl (fig. 2, E) made of a triangular bone splint. It is dark in color, similar to that of the fossil human skull. According to Pei, it is distinguishable from that of the Neolithic age in having a short pointed portion and in the scraping process by which it was made.

The fossil human skull

The skull vault is fairly complete. Most of the facial bones are missing; preserved are only a portion of the body and the alveolar and palatal processes of the maxillae and the horizontal parts of the palate bones composing a complete bony hard palate. All upper teeth are lost with the exception of the root of the left second premolar in its socket. The outer walls of all tooth sockets are broken off except those of the left second premolar and the right second and third molars. Only small pieces of the basal parts of the nasal bones are preserved. All specimens are of darkish color and moderately fossilized. Judged from their similar color, the degree of fossilization and the nearness of the site of the discovery, the cranial parts and the facial parts probably belong to the same individual.

The skull as viewed from above (fig. 2, B) is slightly asymmetrical. The parietal eminence of the right side projects more laterally and slightly anteriorly than does the left. The squamous part of the occipital bone projects further posteriorly on its left than on its right side. These asymmetries are evidently natural. When the skull is viewed from below, the frontal squama projects markedly anteriorly on the right side, and the occipital squama projects markedly backward also on the right side. The left temporal bone dips slightly inward. This clearly indicates that the skull was somewhat distorted by pressure from the outside. It can be inferred from the distortion that the position of the skull was originally with its right side mainly facing downward. Due to the great

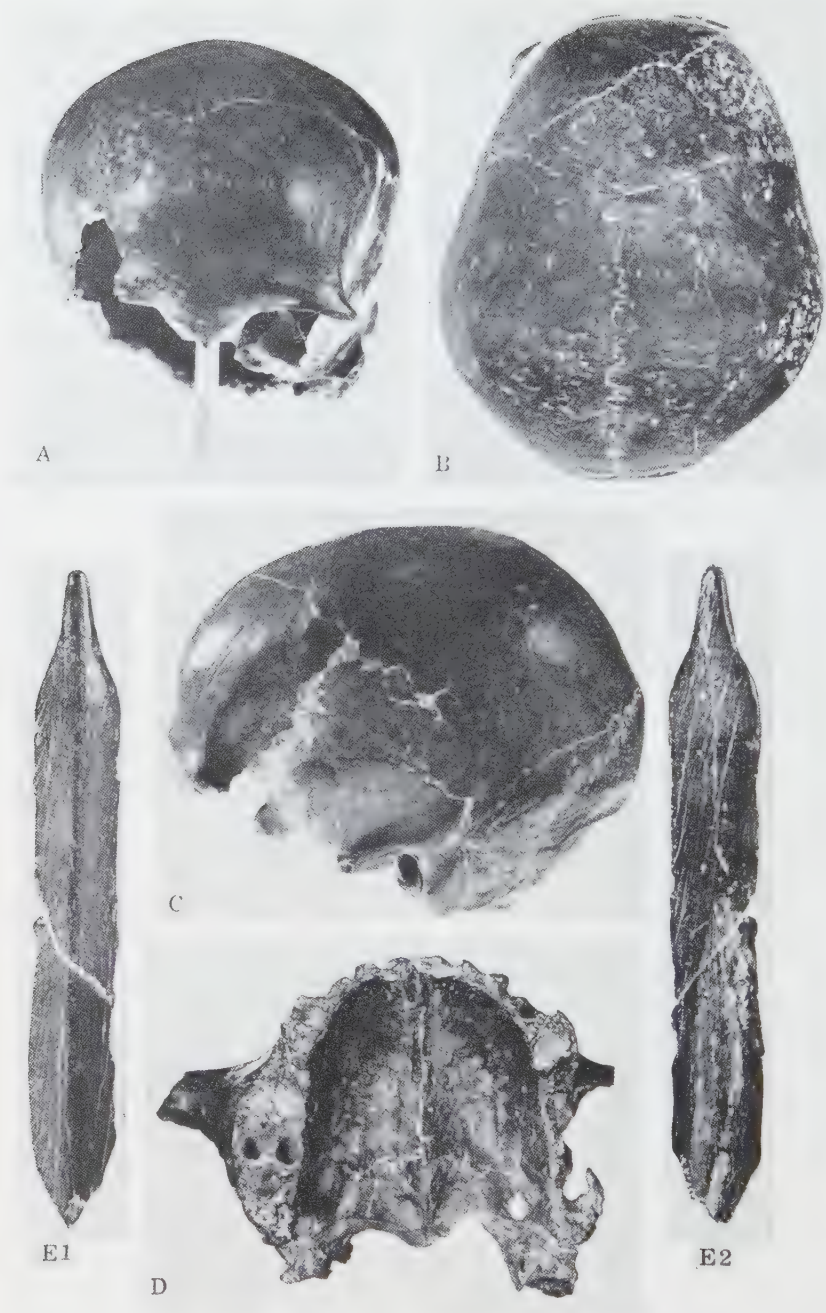


Fig. 2 The Tzeyang skull and Tzyang bone awl. A, frontal view, $\times \frac{2}{5}$; B, top view, $\times \frac{2}{5}$; C, lateral view, $\times \frac{2}{5}$; D, bony hard palate, inferior view, $\frac{1}{5}$; E, bone awl: 1, convex side, 2, flat side, $\times \frac{1}{5}$.

pressure from the upper side, the right temporal bone was gradually completely crushed and the frontal and occipital squamae were shifted forward and backward respectively on the right side as described above.

The skull is small and smooth. The vault is high and the forehead fairly full. The occipital portion is rounded and rough. The supraorbital ridges are prominent. A fairly well-developed median sagittal crest is present. Both parietal and frontal eminences are strongly projecting. The temporal lines are weak. The mastoid process and the supra-mastoid crest as seen on the left side are very massive. The mandibular fossa is rather deep and wide.

The maximum length of the skull is 169.3 mm, breadth 131.1 mm, with a mesocranic cranial index of 77.4. The horizontal circumference of the skull above the brow ridges is 473 mm. The auricular height is 110 mm and the breadth-height index 84.0. In modern man the average breadth-height index is 85.3 (75.6–93.2). Thus the calvaria of the Tzeyang skull is relatively slightly lower than that of modern man, though it is still within the range.

On the external aspect of the skull, all sutures are evident though knitted together. Only at the middle but slightly left part of the coronal suture there is indication of the beginning of closure. In modern man the external sutures of the skull generally begin to be fused at the age of 20 years. However, external suture closure has very great individual variation and is not very reliable for determining the age of the skull. On the other hand, internal suture closure is relatively more regular and more reliable as a basis for age determination.

Upon cleaning the internal surface, it was found unexpectedly that almost all sutures are fused. According to the standard for modern man this would represent an age of over 50 years. A fairly large frontal sinus can be observed in the radiograph of the skull, also indicating the advanced age of the skull.

The bony hard palate (fig. 2, D) reveals that the portion of the median palatine suture in the horizontal parts of the

palate bones are fused completely, but the remaining portion of the suture and the horizontal palatine suture are patent. In modern man, the posterior portion of the median palatine suture begins to fuse at the age of 31–40 years of age.

The alveolar processes of the maxillae clearly show pathologic changes. Judging from the alveolar processes, Tzeyang Man suffered from serious dental disease before death. The teeth are all lost, except the broken root of the left second premolar remaining in its socket. The alveolar process bearing the left three molars is seriously damaged: bony septa between the teeth and their roots and their buccal walls are all broken off; a very irregular bony scar is seen in the remaining lingual walls where the bony tissues are dense and their trabeculae are coarse and have no definite arrangement. These all serve to indicate that the bony tissue was formed by bony regeneration after a chronic inflammation before death. Thus it can be inferred that Tzeyang Man suffered from chronic local bone marrow inflammation or chronic alveolar abscess on the left side, the three molars of which were lost before death. There is also a small hole at the bottom of the maxillary sinus which may be a sign that the inflammation had already spread into it.

The bony tissue of the sockets of the left medial incisor, left canine and first premolar, of the right medial and lateral incisors, right canine, first premolar and the second and third molars, is normal in structure and shows no bony reparation, so that these teeth were lost after death.

The gap behind the right premolar represents the site where the second premolar was originally situated. The tooth was lost before death and bony regeneration filled the socket. The gap behind the left second premolar, originally the socket of the first molar, was formed by the reparation of the anterior wall of the tooth socket.

The root canal of the left second premolar is almost invisible roentgenographically.

The thin-walled maxillary sinus is very large, and extends anteriorly to the first premolar and posteriorly to the third molar.

Since the alveolar processes of the Tzeyang skull suffered from a kind of dental disease which took a long time to develop, and the root canal of the left second premolar is extremely narrow, and the maxillary sinus of large size, the Tzeyang skull certainly belongs to an individual over middle age. These agree with the state of the cranium described above. Thus it can be determined that the Tzeyang skull belongs to an individual of over middle age; judging from the condition of the sutures of the internal side of the skull the individual was probably over 50 years old.

The sex determination of the Tzeyang skull is closely connected with its age. The skull is small, its surface is smooth and the forehead is fairly full. These indicate a female individual. The prominent supra-orbital ridges and the massive mastoid process may be regarded as primitive features. The Tzeyang skull has prominent frontal and parietal eminences which are characteristics of infantile skulls; but an adult female skull may usually retain these infantile features. Accordingly, Tzeyang Man is determined to be a female individual of over middle age.

The Tzeyang skull is ovoid in vertical view. The parietal tuberosities are very prominent, and the greatest width of the skull lies at the maximum curvatures of both tuberosities. The supraorbital ridges are more prominent than those of modern man of similar age and sex. The inner medial or supraciliary arches are almost connected to form a horizontal torus, but the outer or supraorbital portions extend only to the center of the orbits and then gradually disappear. The left zygomatic process of the frontal bone is preserved and it seems to be more robust and salient than that of modern man. The sagittal crest extends from the level of the frontal tuberosities and extends upward and posteriorly and gradually disappears after reaching the middle portion of the parietal bone.

In lateral view (fig. 2, C) the prominent supraorbital ridges are visible in front and the round and blunt occipital behind. The occipital squama is markedly thickened. The opisthocranion is situated high, but nearer to the inion than to lambda.

Thus, the calvarial height index, bregma position index, bregma angle and frontal angle obtained on the base lines of glabella-opisthocranion and glabella-inion (fig. 3) are all larger than those figures recorded by Kroeber ('48).

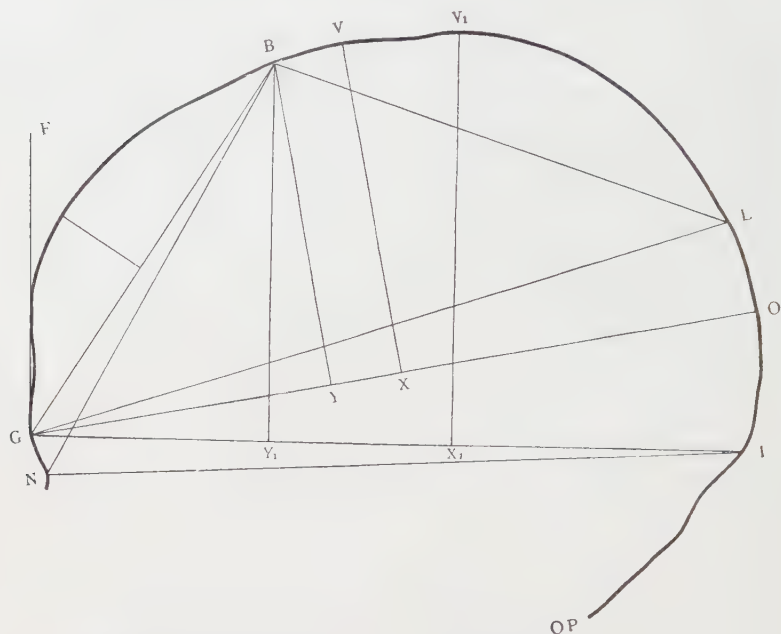


Fig. 3 Mid-sagittal craniogram of the Tzeyang skull, $\times \frac{1}{3}$.

The position of bregma is more posterior than that of modern man. The length of the frontal arc represents about $\frac{1}{3}$ of the total median sagittal arc from nasion to opisthion in modern man, i.e., the bregma lies at the junction of the anterior and the middle $\frac{1}{3}$ of the whole arc. The length of the total arc of the Tzeyang skull is 354 mm, while that of the frontal arc is 126 mm, much larger than $\frac{1}{3}$ of the whole arc and the position of bregma of the Tzeyang skull lies more posteriorly than that of modern man. In some Neanderthal skulls, the bregma is situated further posteriorly than it is in modern man; in *Sinanthropus* it is still further backward than that of Neanderthaloids. The position of the bregma is related more or less to the degree of curvature of the forehead.

The length of the chord of the sagittal margin of the frontal bone is 109 mm; the chord-arc index is 86.5. In *Sinanthropus*, the index is 89.9, while that of modern man is 85.7, indicating that the frontal bone of *Sinanthropus* is flatter than that of modern man, while that of the Tzeyang skull is also slightly flatter than that of modern man.

The reliable method to express the curvature of the parietal bone in median sagittal direction is to calculate the chord-arc index of its sagittal margin. The greater the index, the flatter the bone.

The parietal bone of the Tzeyang skull has the following measurements: arc 121 mm, chord 110 mm, with an index of 90.9. The index of *Sinanthropus* is 94.3, while that of modern man is 89.7. Thus the parietal bone of *Sinanthropus* is much flatter than that of modern man, while that of the Tzeyang skull is also slightly flatter than that of modern man in general.

The arc of the occipital bone of the Tzeyang skull is 107 mm. The length of its chord has not been measured owing to its distortion.

Thus, the calvarial height index of the Tzeyang skull is:

$$\frac{VX}{GO} \times 100 = \frac{77}{170} \times 100 = 45.3$$

$$\text{bregma position index} = \frac{GY}{GO} \times 100 = \frac{71}{170} \times 100 = 41.8$$

$$\text{bregma angle} = 47.5^\circ$$

$$\text{frontal angle} = 81^\circ$$

TABLE 1

Comparison of skull measurements of different human fossils

(All after Kroeber, '48 except the Tzeyang skull)

GROUPS	CALVARIAL HEIGHT INDEX	BREGMA POSITION INDEX	BREGMA ANGLE	FRONTAL ANGLE
Living races	51-59	—	—	—
8 Cro-Magnon	46-55	28-37	46-57°	74-90°
Tzeyang	45.3	41.8	47.5°	81°
9 Neanderthal	33-43	33-40	38-49°	50†-74°
<i>Sinanthropus</i> 2, 3, 10, 11, 12	35-41	37-42	38-45°	56-63°
<i>Pithecanthropus</i> 1, 2	33-37	36-43	38-43°	48-55°

From the above table, it is clear that the Tzeyang skull occupies a position of an early member of *Homo sapiens*.

The zygomatic arch was largely crushed, so it is difficult to know its shape and prominence. However, judging from the remaining basal portion of the zygomatic process of the left temporal, it can be determined that the zygomatic arch bridges over the temporal fossa for a considerable distance. The basal portion of that part of the zygomatic process which is preserved runs more postero-superiorly than that of modern man; it extends backward to join the well-developed supra-mastoid crest which ends abruptly at the temporo-parietal suture and forms a sharp triangular ridge; from the tip of the latter the inferior temporal line begins.

The length of the median sagittal arc of the occipital plane is 57 mm, while that of the nuchal plane is 50 mm, with an index of 87.7. In *Sinanthropus* the occipital plane is shorter than or equal in length with the nuchal plane, with an average index of 123 (100-144); in modern man, on the contrary, the index is 62.3 (52.4-71.2). Tzeyang Man is more primitive in this respect than modern man.

The orbital portion is largely broken off; only the left supra-orbital margin is completely preserved with a small piece of the orbital roof. The supraorbital margin is straight. The fossa glandulae lacrimalis behind it and medial to the zygomatic process of the frontal bone is more shallow and wide than that of modern man. It is interesting to note that the orbital roof of *Sinanthropus* was very flat.

On the internal surface of the occipital well-developed eminentia cruciata separate the upper two fossae occipitalis cerebrealis from the lower two fossae occipitalis cerebellaris. However, there is an important difference between Tzeyang Man and modern man in one respect. In modern man, the fossae occipitalis cerebellaris are wider and deeper than the upper two fossae. In Tzeyang Man, the condition is the reverse and the cerebral fossae are wider and deeper than the cerebellar fossae. Similar situations exist in *Sinanthropus* and Neanderthals.

Weidenreich ('43) pointed out that in both *Sinanthropus* and anthropoids there are smaller occipital planes and larger nuchal planes for the attachment of nuchal muscles. In the process of human evolution, the nuchal muscles were reduced while the brain increased in volume. The nuchal plane decreased in size and the occipital plane increased; in other words, the inion as the boundary of the two planes shifted downward toward the foramen magnum. On the other hand, the change of the position of the internal occipital protuberance was due to expansion of the cerebellum in the process of evolution; its additional space needs caused the upward shift of the horizontal arms of the eminentia cruciata. Thus, the occipital cerebellar fossae came to occupy a larger area while the occipital cerebral fossae retained their original size. In addition, the median sagittal length of the arc of the occipital plane increased and that of the nuchal plane of the occipital squama decreased relatively from *Sinanthropus* to modern man. At the same time, accompanying the enlargement of the brain in the process of evolution, the occipital lobe of the cerebrum and the cerebellum increased relatively. But the enlargement of the occipital plane was sufficient to lodge the enlarged occipital lobe, so the occipital cerebral fossae in modern man are relatively smaller and shallower. Owing to the enlargement of the cerebellum the occipital cerebellar fossae became larger and deeper.

On the Tzeyang skull there is only a trace of a boundary between the nasal floor and the anterior surface of the maxillae at the lower margins of the piriform aperture. On the anterior surface of the maxillae below the lower margin, there is a large and deep prenasal fossa on each side; the fossa extends laterally to the canine prominence. This fossa is usually considered as a primitive feature.

The bony hard palate is 42.6 mm long, 39.0 mm broad, with an index of 91.3. The upper dental arch is U-shaped. The oral surface of the bony hard palate is rugous like that of modern man. There is a slight torus palatinus. The incisive foramen is very large and the palatine foramina are also larger than

those of modern man. There is no trace of the incisive suture as in *Sinanthropus*. In different races of modern man, trace of the suture exists in over 50%, even in adults.

The Tzeyang skull bears some resemblances to the Choukoutien Upper Cave Man: the large and deep prenasal fossae, the sagittal crest-like elevation, the flattening of the upper parietal area on either side of the sagittal suture, and the relatively high and narrow nose, etc. On the one hand there are resemblances to *Sinanthropus*: the sagittal crest, the torus angularis, the flat orbital roof, the well-developed articular tubercle and the absence of a postglenoid process. This would seem to indicate that they have a certain relationship.

CONCLUSION

The Tzeyang locality probably has two groups of animals, one older than the other. The older fossils are *Stegodon orientalis*, *Rusa unicolor*, and *Rhinoceros sinensis* which are generally regarded as Middle Pleistocene in age; the younger are *Homo sapiens*, *Muntiacus*, *Mammonteus primigenius* which are Late Pleistocene in age.

The geologic age of the Tzeyang Man is ascertained from the study of mammalian fossils, stratigraphical observations, and the characters of the human fossil itself, to be earlier Late Pleistocene.

The human skull is a female individual over middle age. Judged from the features of the skull, from the values of the calvarial height index and the bregma index, the bregma angle and the frontal angle, the Tzeyang Man represents an early form of *Homo sapiens*, more primitive than the European Cro-Magnon people and the Upper Cave people of Choukoutien. Thus Tzeyang Man is the earliest fossil representative of the Neanthropic stage so far found in China.

The alveolar processes of the maxillae show that Tzeyang Man suffered from serious chronic local bone marrow inflammation of chronic alveolar abscess before death.

The Tzeyang skull is the most complete fossil human skull found since 1949. The importance of the discovery lies in the

fact that it is the first fossil human skull found in South China, while other human fossils such as *Sinanthropus*, the Ordos tooth and the Upper Cave people were all found in North China. However, the Tzeyang skull bears some resemblance to the Upper Cave Man on the one hand and with *Sinanthropus* on the other. This new discovery provides new data on the origin of the Chinese people and on the distribution of Paleolithic man in China.

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A FURTHER ADOLESCENT AUSTRALOPITHECINE ILIUM FROM MAKAPANGGAT

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TWO FIGURES

The first pelvic fragments of *Australopithecus prometheus* to be recovered were an almost complete left ilium MLD 7 (see figs. 1 and 2) and the major portion of a right ischium MLD 8 of an adolescent individual deemed to be masculine (Dart, '49). The two fragments came from the same small block of grey breccia and were deemed to have belonged to the same individual as furnished the adolescent male mandible MLD 2 discovered during the same season's work (Dart, '48).

On April 30, 1956 during the development of another block of grey breccia stored in the Bernard Price Institute for Palaeontological Research a further adolescent left ilium of similar age (MLD 25) was discovered by Mr. James Kitching which, from its lighter and more slender build, I consider to have been female (see figs. 1 and 2 drawn by Miss V. de Wet).

An extended comparison of the anatomy of this second ilium with that of the first specimen forms the subject of a contribution which was forwarded to Dr. M. R. Sahni in April 1957 for the D.N. Wadia Jubilee number of The Journal of the Palaeontological Society of India, which has been delayed in appearing and may not be easily accessible to all readers of this journal. At the editor's request I am therefore summarizing here the main facts concerning the new discovery.

Assuming the sex diagnosis to be correct the antero-posterior length of this adolescent female ilium is 102 mm, slightly less than in the male (108 mm); but the distances from the anterior and posterior iliac spines to the acetabulum are definitely greater than in the male. It will be remembered that the principal features in which the first, or male australopithecine ilium diverged from the adolescent anthropoid, and resembled the adolescent human bone (Dart, '49) were the shortening and widening and the twisting of the flat iliac blade (the anthropoidal plate of Reynolds, '31) into a volute presenting two concavities: the anterior concavity facing inwards and the posterior one outwards. The approximately coronal plane which the iliac blade occupies in the anthropoidal body thus becomes twisted anteriorly so that in the australopithecine body it assumes a position almost in the sagittal plane as in man.

The new ilium suffered damage prior to fossilization which removed a triangular segment of the blade and a considerable portion of the crest. The retention of the critical anterior and posterior portions of the crest has facilitated reconstruction of the missing portion. There is no doubt from its similarity to the earlier specimen (MLD 7) that it, too, is australopithecine and that it is of similar, if not identical, age. The adolescent boy, to which the lower jaw and presumably also the adolescent pelvis belonged, was killed by a bone-smashing blow on the chin from a club or fist. Did brother and sister share here in death the same cannibalistic fate?

A comparison of the iliac element of the first (male) adolescent pelvis with those of the chimpanzee, Bushman and Negro showed that:

1. The lateral or gluteal aspect of the juvenile male australopithecine was about 10% greater than that of a male juvenile Bush ilium.
2. The juvenile australopithecine and some Bush adolescent iliac crests have no localized cristal tubercle, but a generalized thickening of the anterior cristal region.

3. The anterior superior and anterior inferior iliac spines in *Australopithecus prometheus* are well-developed and closely approximated to one another. In consequence, as compared with anthropoids, the inguinal ligaments and abdominal wall musculature were relatively strengthened and the sartorius muscle acted with increased advantage upon the knee from above, while the straight head of the rectus femoris and Y-shaped ligament of Bigelow operated with correspondingly greater force and precision upon both the hip-joint and knee-joints.

4. The posterior part of the australopithecine iliac blade is phenomenally thick as compared with the anthropoid ilium and even exceeds the adolescent Bush ilium in thickness, especially in its lower part. Hence the posterior pelvic (deeper part of the long posterior sacro-iliac and sacro-tuberous) ligaments must have been much more powerful, which implies not only a stronger hamstring musculature, but also a bigger gluteus maximus, with whose attachments these ligaments are so intimately concerned.

5. The sacro-pelvic aspect of the australopithecine, as compared with the chimpanzee ilium has an auricular surface of increased size and complexity, a retro-auricular surface of virtually double the size, and greatly expanded pre- and post-auricular portions.

In order to compare the second, or female ilium with the first, or male specimen of *A. prometheus* two figures were prepared (figs. 1 and 2). In the first figure dioptographic tracings of the inner and outer aspects of the bones as they lay on the table, were oriented on horizontal lines, drawn from the tips of the anterior iliac spines and 20° above lines from the same point and running tangentially to the inferior borders of the auricular surfaces of the ilia. For the second figure dioptographic tracings were made from the anterior, posterior and superior aspects with the bones maintained in as nearly vertical a position as possible. In each pair of figures the male specimen is on the left side, the female specimen on the right side.

During these manipulations the first, or male ilium sustained a fall and broke almost vertically through the ilium along one of the split-lines (some of which are indicated in the figures) above the acetabulum. Advantage was taken of the accident to

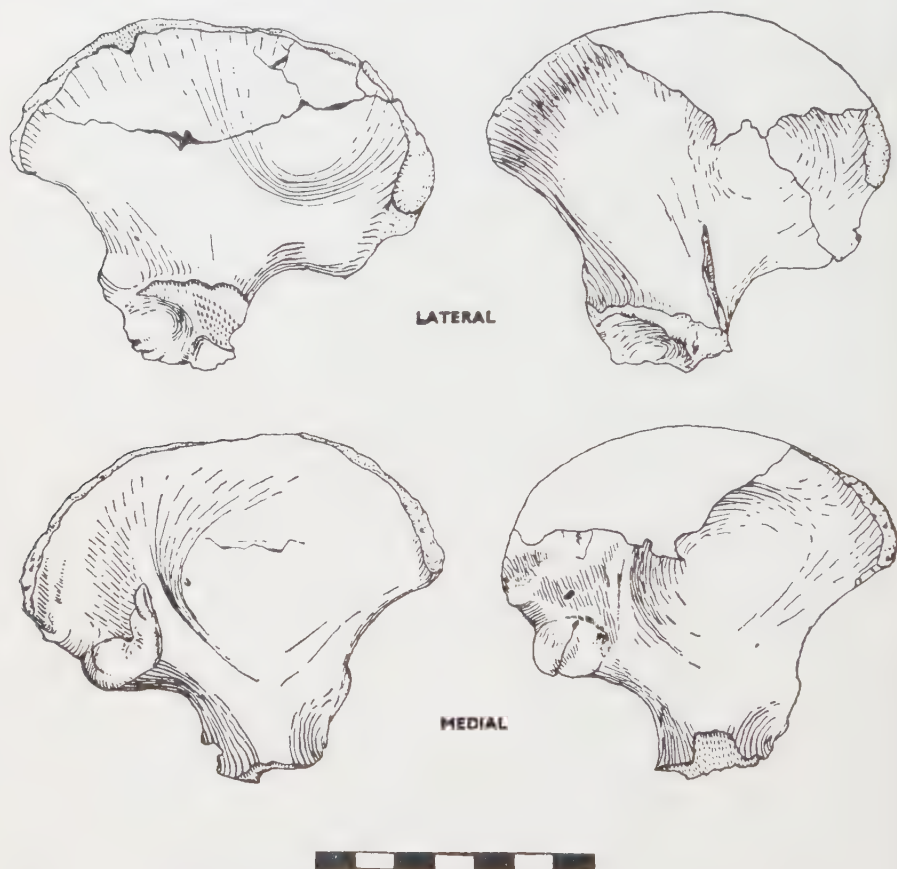


Fig. 1 Dioptrigraphic tracings of the inner and outer aspects of the Makapansgat australopithecine ilia; MLD 7 on the left and MLD 25 on the right of each pair of drawings. $\times \frac{1}{2}$.

add to the second figure a further dioptrigraphic tracing of the male australopithecine (left) adolescent ilium, and to compare it with a corresponding tracing of a Bush adolescent, female ilium (right) sectioned in similar fashion vertically. The

principal difference is in the greater thickness of the compact bone medially, and especially laterally in the australopithecine as compared with the Bush ilium.

From the first figure it is patent that the female differs from the male *A. prometheus* in the greater distance between the anterior superior and anterior inferior iliac spines; also the anterior border is less arcuate in the female. The male ilium is long antero-posteriorly and low supero-inferiorly, i.e., stocky in build as compared with the female, which is more sculptured. Thus, the supra-acetabular groove for the reflected head of the rectus femoris is deeper in the female and the female ilium shows a grooving below the iliac crest and an outward flaring of the blade above it. Consequently, the external convexity of the anterior half of the gluteal surface is more pronounced in the female and the external concavity of the posterior half deeper than in the male individual (compare the view from the superior aspect in figure 2).

On the sacro-pelvic surface one notes the difference in form of the auricular surface (L-shaped in the male and elliptical in the female) and in its position (displaced relatively further posteriorly, suggesting a relatively increased antero-posterior diameter in the female). In both retro-auricular surfaces there is a nipple-like process and a ridge running anteriorly from it, apparently for the attachment of stout interosseous sacro-iliac ligaments. These bosses are well displayed in the posterior views (see fig. 2).

The second figure not only displays the features already emphasized, but also exhibits the sudden and more marked incurving of the anterior portion of the iliac crest in the female ilium (as seen from both the superior and anterior aspects). Also, the greater delicacy and moulding of the female bone is also plainly apparent.

The prime significance of these two ilia is that, despite their youth, they afford the first information about sexual divergence in the australopithecine pelvis. Moreover the shattering of the bone has afforded unexpected evidence of the thickening of the compact bony layer or pillars of bone especially on the

lateral aspect of the ilium between the iliac crest and the acetabular cavity. In addition the natural split-lines in the fossils do not show an anthropoid pattern, as Mednick ('55) imagined possible, but a typically human pattern. These juvenile ilia

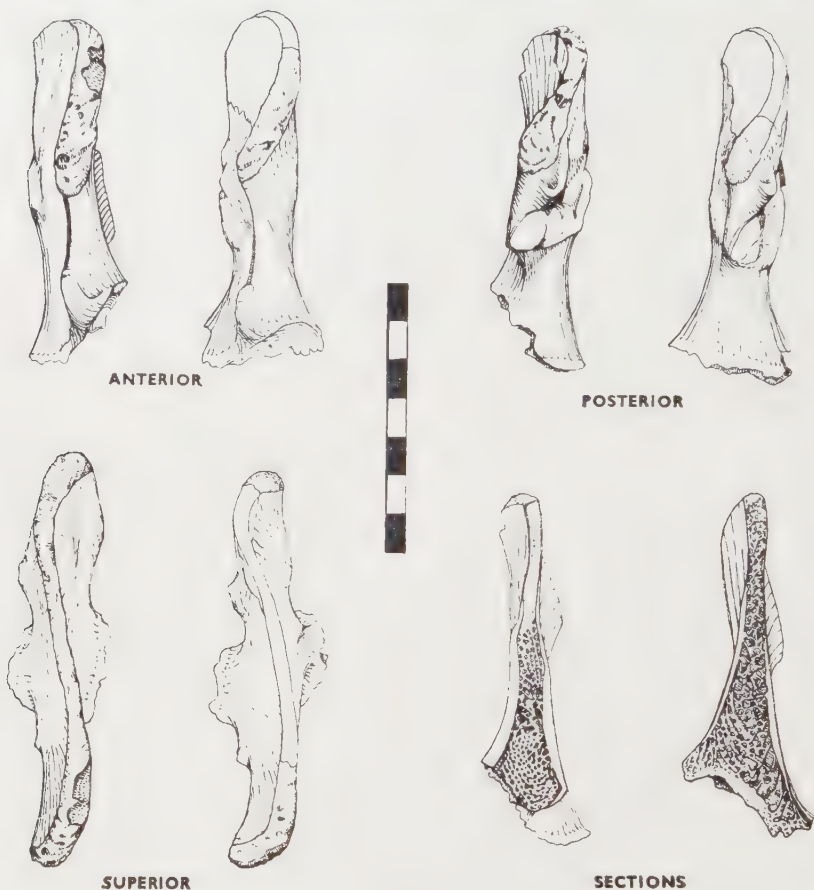


Fig. 2 Dioptrigraphic tracings of the anterior, posterior and superior aspects of the Makapansgat australopithecine ilia; also, a vertical section of specimen MLD 7 (left) and a female Bush adolescent. $\times \frac{1}{2}$.

show that the adolescents of *A. prometheus*, both male and female, simulate *Homo sapiens* (especially the Bush variety) in their iliac structure so closely that it would be unreasonable to imagine that bipedalism was any less distinctive of their gait than it is of living human beings.

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HAS STATISTICS RETARDED THE PROGRESS OF PHYSICAL ANTHROPOLOGY?

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Physical anthropologists, under the influence of workers such as Karl Pearson, at an early stage introduced the use of statistical methods into their discipline, and the use of means, standard deviations (or, earlier, probable errors), and correlation coefficients became a characteristic feature of papers and books dealing with the subject. In this utilization of statistics anthropologists were in advance of most other biologists.

Today nobody doubts the value of statistical methods in biological research. They assist in planning the proper experiments to investigate a question, and they are often indispensable in assessing the significance of the results of experiments. It may therefore come as a shock to some readers if it is suggested that the use of statistical methods has held back the progress of physical anthropology in certain respects. Nevertheless, there are reasons for believing that this has been the case.

I have previously (Boyd, '50) summarized the arguments of a famous worker whom many regard as the founder of modern statistics, R. A. Fisher. Fisher ('36) asserted that in craniometry (and at one time craniometry and physical anthropology were virtually synonymous) the theoretical concepts lagged far behind the mass of observational material which accumulated. Fisher thought that this was partly due to the sheer magnitude of the program which the energy of its founders sketched out, and partly to an "intuitive" confidence, very difficult to justify, that by amassing sufficient

statistical material all difficulties would ultimately be overcome. In other words, reliance on statistical methods led to an uncritical accumulation and publication of measurements the heads of living men and of skulls, without adequate reflection as to *what* measurements were worth making. Most contemporary workers would probably now agree with this criticism.

The statistical methods employed were generally sound enough; the difficulty was that their application sometimes involved tacit assumptions which we now see are untenable. Fisher ('36) pointed out that the once popular "coefficient of racial likeness," in addition to other faults, took no account of the correlations or covariations of the various measurements of one and the same skull, but treated them as if they were statistically independent, which they definitely are not.

I have previously argued (Boyd, '50) that one of the reasons metrical data are less informative than, for example, blood grouping data, is that genetic analysis of metrical features has not been carried through, and in most cases not even started. I attributed this failure partly to the apparent improbability that such attempted analysis would quickly yield publishable and thus indirectly financially rewarding results. Waddington ('57) has recently suggested that this failure results from one of the dangers which statistical methods have "always" brought in their train. He believes that these dangers have affected both the study of human populations and the study of heritability in animal breeding.

In the first place, according to Waddington, there has been a tendency to regard a refined statistical analysis of incomplete experiments as making it unnecessary to carry the experiments further or to design more penetrating experiments. This is similar to Fisher's belief, stated above. Waddington says "For instance, if one takes some particular phenotypic character such as body weight or milk yield, one of the first steps in an analysis of its genetic basis should be to try to break down the underlying physiological system into a number of more or less independent factors. Are some genes

affecting the milk yield by increasing the quantity of secreting tissue, others by affecting the efficiency of secretion, and others in still other ways? I... discussed a case of variation in the quantity of vein formed in a certain region of a *Drosophila* wing in which it was particularly clear that the genetic systems fell into distinct physiological groups . . . A normal quantity of venation may be present either as a single contiguous vein or as a shortened vein to which a piece is added on the side."

In the second place, says Waddington, "the statistical techniques at present available, although imposing and indeed intimidating to most biologists, are in fact very weak and unhandy tools." Statisticians might not agree, but Waddington goes on to point out that all attempts to analyze variation into genetic and environmental components, for example, are based on drastic oversimplifying assumptions. Even after half a century of development, the statistical theory has to leave out an important term which contributes to genotype-environment interactions. Waddington also points out other deficiencies in the current treatment of such problems.

Waddington's book is not easy reading, but it should be read by all physical anthropologists. The result will not be, of course, to make us give up all use of statistical methods. It might however have the effect of leading to a more careful examination of the assumptions back of any particular treatment of a particular problem, and might encourage the tendency, already plainly evident, to think more in terms of populations and genetics and less in terms of individual crania and nasal indices.

SUMMARY

It is argued that the use of statistical methods in physical anthropology, although no doubt useful, and something which should be continued, has in the past retarded the progress of the discipline, by leading to a false feeling of security in the uncritical accumulation of great masses of measurements and by discouraging attempts at physiological and genetic analysis of human traits.

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BRIEF COMMUNICATION

THE PHYSIQUES OF EXPLORERS

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In the summer of 1956 an expedition of the British Schools Exploring Society, consisting of 9 leaders and 50 boys, spent 6 weeks in central Iceland. The purpose of these annual expeditions is to provide selected schoolboys, whose ages vary from 16 to 19 years, with a training in self-reliance and leadership, and with a chance to participate in scientific work in the field.

The opportunity was taken during the 1956 expedition to investigate both the changes in body weight and the somatotypes of the 50 boys, and it is with the latter study that this paper is concerned.

METHOD

The subjects were somatotyped anthroposcopically by Dr. J. Tanner using enlargements from 35-mm negatives taken in the field at the beginning of the expedition: three views were taken of each subject according to the technique described by Sheldon et al. ('40), but no attempt was made to obtain photographs suitably standardized for photogrammetry. Indices derived from Sheldon's "height over the cube root of weight" tables were used in the assessment, and although the somatotyping of the group proved more difficult than that of laboratory posed subjects, it is thought that a substantial degree of accuracy was achieved.

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RESULTS AND DISCUSSION

The complete VIth form of an English Public School² has already been somatotyped by Tanner ('57) and makes a convenient control group with which to compare the physiques of the "Explorers." The latter were drawn from a rather more varied social background than the former, but this cannot account for the observed differences, since the effect of social class on physique is small (Tanner, '54) and in the opposite direction to the results obtained (table 1).

TABLE 1

Comparison of the mean somatotype ratings for the "Explorers" and Public Schoolboys

	ENDOMORPHY	MESOMORPHY	ECTOMORPHY
Explorers (n = 50)	2.75	3.89	4.08
Schoolboys (n = 88)	3.14	3.80	3.62
Difference	- 0.39 ¹	+ 0.09	+ 0.46 ¹
t	2.58	0.51	2.08

¹ Significant at 1% level.

t is the ratio of the difference to its standard error.

It can be seen that the "Explorers" are significantly less endomorphic and more ectomorphic than the control group, but there is little difference in mesomorphy.

Only 1 in 7 of those boys who applied for a place on the expedition were accepted by the interviewing committee and consequently a selection bias is a possible explanation for the observed differences. But such a bias is improbable, for a moderate predominance of endomorphy is inconspicuous in young males and only the extreme examples of this somatotype would be likely to attract attention; such extremes are relatively rare. The alternative and more acceptable explanation is that the challenge of physical effort and discomfort appeals particularly to the type of person whose physique is relatively high in ectomorphy and low in endomorphy.

² One of the anomalies of the British system of education is that the private and fee-paying schools are known as "Public Schools." To all intents and purposes their VIth forms comprise all the older boys and not merely the more intelligent ones.

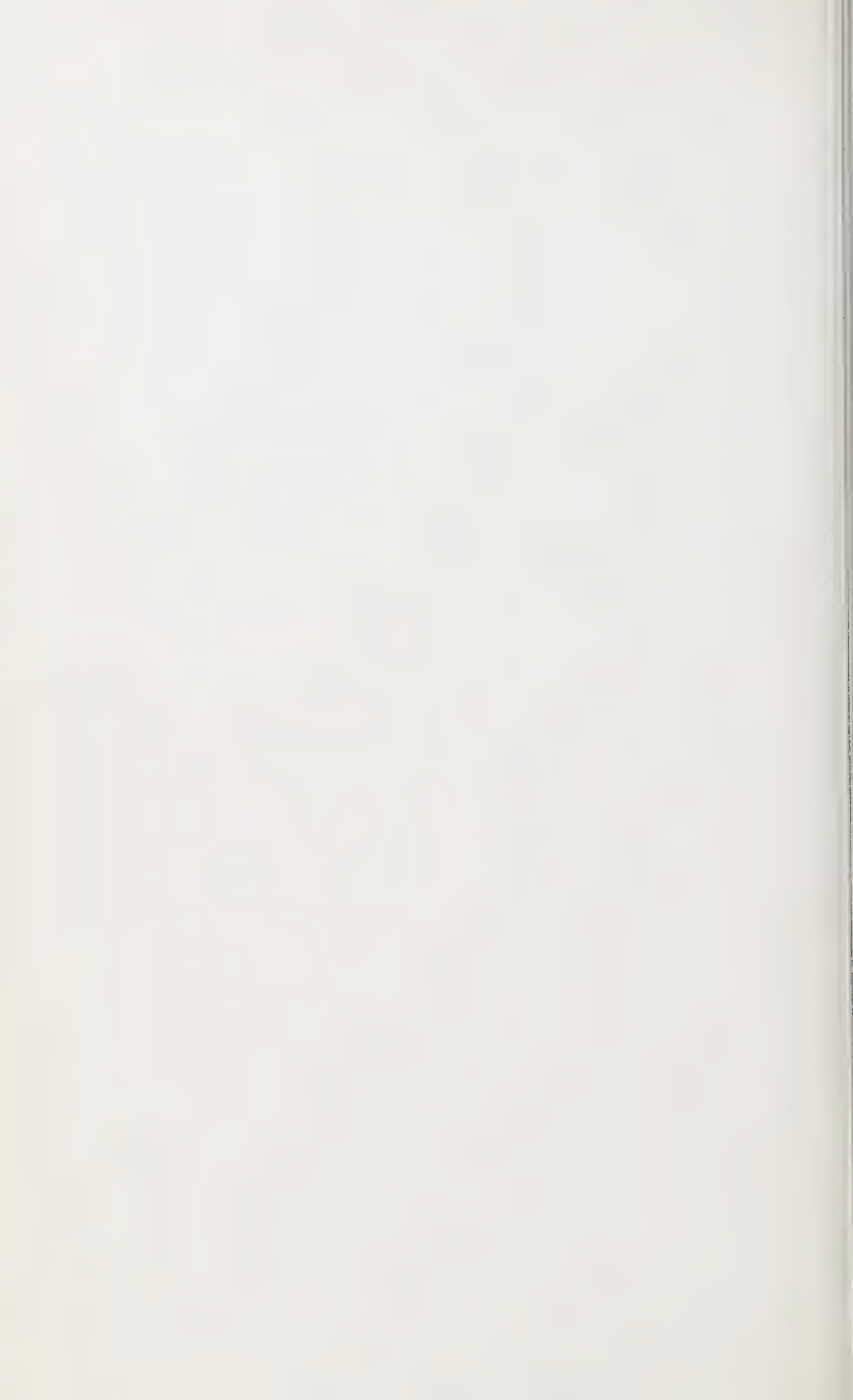
It has been shown that an individual's choice of career is associated with his type of physique (Tanner, '54); so also it would seem is the urge to join an expedition to Iceland.

ACKNOWLEDGMENTS

Besides my debt to all the members of the expedition, I wish to thank Dr. H. B. Jones for his assistance in the field work, Dr. H. E. Lewis for his helpful suggestions, and Dr. J. Tanner for somatotyping the photographs, making available unpublished data, and for his invaluable advice.

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BOOK REVIEW

CHEMICAL ANTHROPOLOGY: A NEW APPROACH TO GROWTH IN CHILDREN. By Icie G. Macy and Harriet J. Kelly. xviii + 149 pp., \$3.75. University of Chicago Press, Chicago, 1957.

Within the span of a single year, not one but two concepts of a new brand of anthropology have been offered. R. J. Williams (*Chemical Anthropology: An open door. Amer. Scientist*, 46: 1-23, 1958) opens his programmatic call-to-arms by the statement that at present the most productive areas in scientific research seem to be those which lie on the borderline between two disciplines. In keeping with this idea, Williams proposes a wedding between the disciplines of chemistry and anthropology. This is not to supersede the Science of Man as presently constituted but to add something new. It is from the chemical study of genetically determined individual differences that the author expects signal advances to come.

The subject is not entirely new. Standard textbooks in biochemistry (cf. B. S. Walker, W. C. Boyd and I. Asimov, *Biochemistry and Human Metabolism*, Williams and Wilkins, 3rd ed., 1957) have sections on genetics (p. 410 f.) and blood groups (p. 430), topics that represent outstanding examples of biochemical individuality. Differences in human dietary requirements, including vitamin requirements, are well established.

Williams' contribution lies in his making clear the serious impediment in the progress of knowledge resulting from the excessive preoccupation of basic medical sciences with the "average" man; in stressing the large scope and potentially profound significance of differential biochemistry — to paraphrase William Stern's pioneering *Differentielle Psychologie* ('11); and in pointing out the need for relating the biochemical differences to significant individual human characteristics. The author carried out studies on individual differences in proneness to alcoholism, in taste thresholds for common substances, as well as on differences in salivary, urinary, and blood constituents. The use of polar coordinates serves well to portray graphically the presence of a high degree of biochemical individuality among his subjects. The uniformity in identical twins and distinctive

metabolic patterns in inbred strains of rats strongly suggest that these aspects of individuality are under genetic control.

The distinctive feature of the Macy-Kelly monograph is its concern with gross body composition, a fundamental facet of human physique exhibiting large inter-individual differences (and intra-individual changes), especially in regard to the fat content. This aspect of body build is largely neglected by Dr. Williams. On the other hand, Drs. Macy and Kelly are almost solely concerned with average age trends, disregarding, by design, the presence of differences among individuals. These are to be considered in a later publication.

The roots of modern anthropological study of body composition may be traced to J. Matiegka's paper (The testing of physical efficiency. *Am. J. Phys. Anthropol.*, 4: 223-230, 1921). The author, much interested in human growth, outlined a technique for a quantitative appraisal of the mass of the main body compartments accessible to anthropometric approach, and provided examples demonstrating the biological significance of analyzing body weight in terms of its anatomical components. Matiegka's approach, providing physical anthropology with its vital "fourth dimension," has been largely bypassed in silence, and the present volume is no exception in this regard.

In subsequent years the studies of body composition continued to receive impetus through a variety of developments. R. E. Scammon, a quantitatively oriented anatomist, portrayed in the early twenties the markedly varying rates at which different organs grow, with special emphasis on the fetal period. In regard to the fat content of the body, the *tela subcutanea* grows precipitously between about the 28th and 40th week of menstrual age (term). Scammon (cf. Edith Boyd, *An Introduction to Human Biology and Anatomy for First Year Medical Students*, 1952, Table 2) provided an equation for predicting from crown-heel length the weight of the anatomically separated *tela subcutanea* and of chemically extracted fat.

R. E. Moulton ('23), concerned with growth and development of farm animals, formulated the concept of "chemical maturity," defined as a state in which the composition of the fat-free mass (analyzed in terms of water, protein, and minerals) approximates constancy. The strongest stimulus to the study of body composition in man came from the work of A. R. Behnke (1941-42), initially an outgrowth of his physiological studies pertaining to deep sea diving. Under his guidance formulae were developed for a densitometric analysis of the weight of the living human body into its "fat" and "lean" fraction. The determinations of total body water, separated into its extracellular and intracellular component, represent the

latest methodological advance along the biochemical lines while important progress has been made in the direct chemical analysis of whole cadavers and in the estimation of skeletal weight.

Most of the work on body composition has been concerned with the adult man. Macy and Kelly attempted to adapt some of the available estimation equations in order to predict the body composition in children. In addition, the authors utilized prediction equations reported in the literature. No original densitometric or hydrometric data were obtained. The reviewer is sorry to report that, on the whole, the authors' treatment of body composition in children is not satisfactory.

Thus the adaptation of the data on the relations between relative body weight and body composition obtained by McCance and Widdowson, was based on the untenable "assumption that the composition of the average child is the same as for the average adult" (p. 73, line 4). The authors themselves have indicated (p. 71), on the basis of the data of Widdowson et al., that there are substantial differences in the fat content of the "child" (22.7%) and "adult" (14.9%). For total body water the values were given as 53.8 and 61.8% of the gross body weight, respectively. These are sizeable differences. In view of the pronounced age trends in body composition during "maturity" (20-60 years of age) and large sex differences, any reference to the fat content of the body in "adults"—without specification of age or sex (as in fig. 5)—is all but meaningless.

It may be noted that a serious error crept into the Macy-Kelly system of analysis due to the fact that they represent "lean body mass," a term by which they incorrectly designate the fat-free mass, as consisting of the extracellular water plus cell mass, with no account taken of bone minerals (p. 69, Terminology).

There is a basic lack of understanding of the procedures involved in the indirect methods for the analysis of body composition. Thus it is said that "McCance and Widdowson measured the amount of cell mass and extracellular water and, assuming that the cells contained 67 per cent by weight of water, calculated the intracellular water" (p. 76). The sequence, in fact, has been quite different. What was actually measured was the "total" (T) and "extracellular" water (E). Their *difference* (T-E) was taken as representing the "intracellular" water (I). *Then*, assuming the water content of "cells" (C), the latter body compartment was calculated ($I = 0.67 C$; $C = I/0.67$).

The use of specific gravity, the second conceptual pillar of the studies of body composition, documents even more strikingly the danger inherent in second-hand contact with the problem. It is said,

without adequate clarification, that the formula developed for estimating fat in adults from specific gravity is not applicable to children. The fact is that the authors did not have to their disposal any valid measurements of specific gravity in children. It was not taken into account that the body volume or the weight under water must be corrected for the amount of air remaining in the lungs and the respiratory passages when water displacement method is being used, before a valid figure for specific gravity (or density) can be obtained. This was not done either by D. E. Zook ('32) or by Edith Boyd ('33) who, in relating specific gravity to stature and age, utilized body volumes measured at mid-respiration. These values, not corrected for the air volume, are too low and, without correction, cannot possibly provide a valid basis for the estimation of body fat or be used for comparison with data on adults.

These are harsh and unpleasant facts, yet they had to be brought out. The reviewer much regrets the necessity for this criticism, especially as he is in complete agreement with the authors' aim: Clearly, changes in size and in gross body weight do not provide a reliable measure of chemical growth. Data on laboratory and farm animals have revealed forcefully the crying and persisting need for describing human physical growth and development in terms of body composition, studied both longitudinally (when changes in size are viewed against the background of invisible chemical additions accounting for the enlargement of organs and tissues) and crosssectionally (body composition at a given time).

If we compare physical anthropology to a pancake, we may note that increases along the circumference—rough, uneven, but vital and growing—have been importantly stimulated by the contact with other disciplines, their problems and their methodology. Science of nutrition is one of these areas. It was in the nutritional context that Dr. Macy and her co-workers began their studies on chemical growth during childhood (4–12 years). A large amount of valuable data was recorded and analyzed in regard to the storage of nutrients in the body of the growing child, together with anthropometric, radiographic and physiological measurements as criteria of the complex changes constituting growth. These data, described in the three volumes of *Nutrition and Chemical Growth in Childhood* ('42, '46, '51), were presented and interpreted in the first part of the present volume. The reviewer has no bones to pick with the authors in regard to this material. The criticism is directed to their use of the new procedures for the evaluation of body weight in terms of body compartments. It should be made clear that these procedures were fully developed,

by various investigators, after Macy's original growth data had been already gathered.

A synthesis of the simpler body measurements with the more complex biophysical and biochemical approaches to the analysis of body composition represents an important task for physical anthropology. The present monograph will undoubtedly stimulate further research in this field, badly needed to fill the existing gaps in our knowledge and to separate the grain from the chaff: "Some established standards of reference will stand the test of time; others will have to be revised; still others will have to be replaced if an accurate and broader interpretation of the data is to be achieved" (p. 4).

The Macy-Kelly concept of "chemical anthropology," defined as an expansion of physical anthropology extended to include chemical growth and its relationship to size and physiological function, is a challenge to the new generation of students of human growth and development.

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BOOK REVIEW

TRAITÉ DE PALÉONTOLOGIE. TOME VII, PRIMATES-PALÉONTOLOGIE HUMAINE. By J. Piveteau. 676 pages, 639 figures and 8 plates. 12,000 francs. Masson, Paris. 1957.

This comprehensive volume is divided into the history of the primates (214 pages) and human paleontology (446 pages). The first section covers the origin of the primates and the Tupaoids, the prosimians (divided into Lemuriformes, Lorisiformes, and Tarsiiformes); anthropoids (divided into Platyrrhines, Cynomorphs, and Anthropomorphs). In each section are reviewed: the general characters of the group, the living members, classification, and paleontological history. The zoological position and evolutionary tendencies of each group are evaluated, and there is an excellent bibliography for each section. The second part on human paleontology is much more detailed and is divided into an introductory section, a description of the human skeleton, the origin of man (*Oreopithecus* and *Australopithecus*), Archanthropines, Paleoanthropines, Neoanthropines, and the problem of mind and the nature of man. There are 16 bibliographies for the chapters on human paleontology, and an excellent index for the whole volume. The index, special bibliographies, and numerous

illustrations make this encyclopedic volume easy to consult. The text is clear, and the author's evaluations of fact and theory are always judicious. The anthropologist will find this the most useful treatise on primate paleontology now available.

The comprehensive nature and encyclopedic character of this volume make it exceedingly difficult to characterize in a short review. It contains descriptions and illustrations of hundreds of primates, and the index alone is in three columns and covers 10 pages. Since every group of primates is illustrated, classified, and discussed, Piveteau has expressed opinions on every major problem in primate classification and human evolution. His evaluations are always careful, and a few of particular interest to anthropologists are briefly noted below.

Parapithecus is considered of uncertain affinities and, probably, not a primate. The pongid and human lines are thought to have separated before the Miocene because the East African Miocene pongids are already specialized apes. *Oreopithecus* also shows that the separation was far back, and Piveteau thinks that *Oreopithecus* might be a direct human ancestor. *Australopithecus* is regarded as too late and peripherally located to be an ancestor of man, but the structure of the australopithecines does shed light on the stages of human evolution. A form such as Ehringsdorf may have been the common ancestor of both the later neanderthals and *sapiens*.

Of the many authors cited, Piveteau seems to have been influenced particularly by Le Gros Clark (on fossil lemurs and apes), Vallois and Weidenreich (on fossil man), and Teilhard du Chardin (on man's place in nature). According to my biases the European fossils are over-emphasized. The La Chapelle neanderthal skeleton receives considerably more space than *all* the australopithecines, and approximately three times the space devoted to the New World monkeys. Africa is regarded primarily as a refuge area, but it appears that many groups of primates must have originated there, and great, tropical Africa probably played a far larger role in human evolution than Europe. Also, although limb bones are well-described in the text, the importance of the dentition seems exaggerated in drawing conclusions. More emphasis on behavior might have led to different evaluation and classification in some cases. However, there will always be differences in interpretation, and the great value of this volume is the way the evidence is presented, illustrated, and discussed. This is a major contribution which will be welcomed by every serious student of the primates.

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